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EVIDENCE FOR A NORTHERN TRANSITIONAL CONTINENTAL MARGIN FLORA IN THE CRETACEOUS (CAMPANIAN TO MAASTRICHTIAN) MATANUSKA FORMATION, TALKEETNA MOUNTAINS, SOUTHCENTRAL ALASKA

A

DISSERTATION

Presented to the Faculty

of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements

for the Degree of

DOCTOR OF PHILOSOPHY

by

Sabra Louise Reid, B.S., M.L.A.

Fairbanks, Alaska

December 2007

UMI Number: 3302510

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Abstract

The Late Cretaceous Matanuska Formation contains shallow and deep marine sediments and nonmarine sediment derived from the Talkeetna volcanic island arc. The sediment accumulated in the Matanuska Seaway, a tectonically active basin on the southern margin of southcentral Alaska. The Matanuska Seaway was contemporaneous with the Cretaceous Western Interior Seaway (CWIS) of North America. Angiosperm pollen taxa from the CWIS have been used to date units and reconstruct both paleolatitude and paleoclimate (Nichols and Sweet, 1993). Comparison of pollen taxa from the CWIS to assemblages from the Matanuska Formation reveals that outcrops at Mazuma Creek, Granite Creek, Syncline Mountain, and Slide Mountain are Late Maastrichtian, while Hicks Creek outcrops are Campanian. During the Late Maastrichtian, the Matanuska Seaway was located south of 75° N latitude.

The presence of ash layers overlain by low-diversity palynofloras with relatively high proportions of spores indicates the presence of volcanic recovery floras within the Matanuska Formation. Palynofloral composition and diversity of the climax vegetation suggest that the Matanuska paleoflora is a northern, transitional, continental margin flora that shares taxa with Late

Cretaceous Pacific Rim floras of the Russian Far East and Japan and continental margin floras of western North America. When combined with coeval assemblages from the Alaska Peninsula, southcentral Alaskan palynofloras of the Late Cretaceous contain the most diverse assemblages of *Aquilapollenites* group taxa known from the North Pacific Rim. The Matanuska Seaway thus represents a coastal dispersal corridor where floras of the North Pacific Rim and western North American mingled.

Within Alaska, the diversity of Late Cretaceous *Aquilapollenites* group taxa increases from north to south. Comparison of the Matanuska Formation palynoflora with assemblages from the interior Lower Cantwell Formation and the Arctic Prince Creek Formation reveals the presence of a north-south paleoecological and paleoclimatic gradient during the Campanian-Maastrichtian. The Matanuska Formation paleoflora suggests that the paleoclimate of southcentral Alaska was warm and humid. Assemblages from the interior Lower Cantwell Formation paleoflora are indicative of a warm, dry paleoclimate, while palynofloras from the Arctic Prince Creek Formation paleoflora record a cooler, more temperate paleoclimate on the North Slope.

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Acknowledgements

For my sister, Susan Leah (Blankenship) Stanley, who listened and encouraged me through this whole process for fifteen years, I give my love.

From the beginning of my educational career my parents, Marion Louise (Delavan) and Ernest Joseph Blankenship, Jr., wished for me to excel. So, although they have been gone for many years, I wish to acknowledge that they provided for the education they believed that I would eventually pursue.

I am eternally grateful that my five children, Stacy, Ralph, Heidi, Bridget and Ingrid, believed in me, and are now following in my footsteps with respect to education. It has always been my goal that they should stand taller than I have.

For my husband, Leroy C. Reid, Jr., PhD, who has encouraged me for the past fifteen years, I give my heartfelt thanks.

My first Professor of Geology, Anne D. Pasch, has my eternal gratitude for her boundless encouragement and support and for setting me on the path so long ago.

For my many committee members, some of whom came and left due to job transfer or retirement, my thanks to them

for staying the course, for their gifts of encouragement and professional advice. They include my first Committee Chair, Mari E. Edwards, PhD, (UAF, moved to Norway); my second Committee Chair, Sarah Fowell, PhD,(UAF); Howard "Bud" Simpson, (ARCO, retired), Roland A. Gangloff, PhD, (UAF, retired); Don Triplehorn, PhD, (UAF, retired); Florence R. Weber, Honorary PhD, (USGS, Emeritus Geologist, retired); Keith Crowder, PhD, (UAF, retired); and Pierre A. Zippi, PhD, of ARCO Alaska (moved to ARCO headquarters, Plano, Texas).

I also have the greatest appreciation for the support from ARCO Alaska for providing lab services early in this project for palynomorph extraction and preparation of slides, and to Carl Sterrett, the ARCO Alaska technician, who did the lab work. Many thanks to Russell Harms, Global GeoLab, Ltd., Medicine Hat, Alberta, Canada, for his excellent work in the most recent years in processing the second half of the palynomorph slides used in this study.

Many thanks to my friends who also served as field assistants over the years, Dennis Clark, Tony DeLucia, Sue Kurtz, Kevin May and his children Simeon and Lizzie Williams-May, my former students Kristy Wallace, Rich Monahan, Michelle Harper, Kim Bolin, Catherine Vyborny-Carter, and my friends Loren Haddix and Norm Lapinskas for

their generous technical computer support. I also wish to thank my true friend, June Champlin, for her many years of encouragement.

And finally, to the memory of my friend, my cousin and fellow geologist, the late Donald Orin Hodges, who loved the Talkeetna Mountains, I dedicate this study.

I. Introduction

Global paleofloral provinces

A paleofloral province is defined by the presence of endemic genera and species of organ fossils, including pollen grains and spores (Herngreen and Chlonova, 1983) and is restricted by their geographic and stratigraphic distribution (Traverse, 1988; Herngreen *et al.*, 1996). The earliest evidence of latitude-parallel paleofloral provinces is from the Lower Carboniferous (Sullivan, 1965). Jurassic and Cretaceous rocks of the Northern Hemisphere are divided into the Siberian-Canadian and Indo-European paleofloristic realms based on megafossil records (Vakhrameev, 1964, 1971, 1972, 1976; Vakhrameev *et al.*, 1970; Batten, 1984). Vakhrameev (1991) and others (Zaklinskaia, 1962, 1963, 1967; Srivastava, 1978, 1981) stated that global division of paleoecosystems into distinct paleofloral provinces parallel to paleolatitudes is clearly evident during the Jurassic and the Late Cretaceous, and that these paleofloral provinces represent discreet paleoclimates.

By the late twentieth century, seven Late Cretaceous paleofloral provinces **(Fig. 1)** were recognized and described. Zaklinskaia (1962, 1963, 1967), reviewing pollen dominant taxa, *Aquilapollenites* and Normapolles, to define

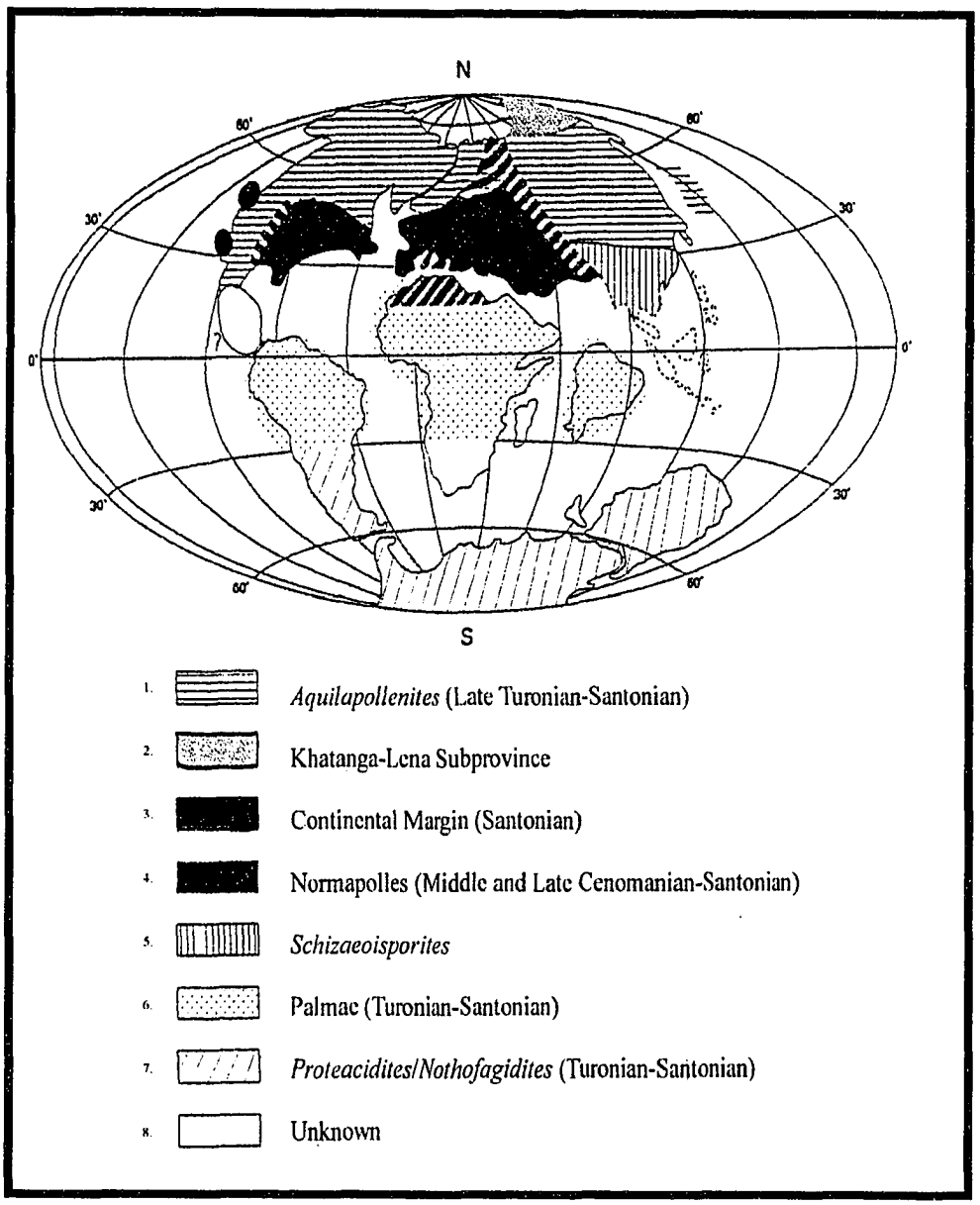

Fig. 1. Late Cretaceous global paleofloral provinces defined. 1. Western (*Aquilapollenites*) Province; 2. Khatanga-Lena (*Azonia recta*) Subprovince; 3. Continental Margin (*Proteacidites* and fern spores) Province; 4. Eastern (Normapolles) Province; 5. Southeast Asia (*Schizaeosporites*) Province; 6. Tropic (Palmae) Province; 7. *Proteacidites/ Nothofagidites* (*Nothofagidites*) Province; 8. southern Africa (unknown paleomicrofloral associations) and Central America, non-existent during the Late Cretaceous(modified from Herngreen *et al.*, 1996).

data from both the Western and Eastern Hemispheres, used the two Late Cretaceous floristic provinces: the *Aquilapollenites* Province of Asia and western North America (including Alaska and Siberia) and the Normapolles Province of Europe and eastern North America.

The *Aquilapollenites* Province, the focus of the present study, is characterized by pollen species of the *Aquilapollenites* Group, *Wodehouseia* of the Oculata Group, *Proteacidites* of the *Proteacidites* Group, and *Cranwellia*, *Erdtmanipollis*, *Kurtzipites*, and *Scollardia* of the *Callistopollenites* Group (Takhtajan, 1969; Srivastava, 1981; Traverse, 1988; Herngreen *et al.*, 1996). Jerzykiewicz and Sweet (1986) further defined the *Aquilapollenites* Province as the "Cretaceous equivalent of the present Boreal Forest realm" which is a subarctic, northern hemisphere forest that is dominated by conifers (Allaby, 1992).

The Normapolles Province includes the pollen genera *Atlantopollis*, *Complexiopollis* and *Trudopollis*. A Late Cretaceous Tropic (Palmae) Province is characterized by the pollen genera *Retimonocolpites*, *Spinizonocolpites*, *Echitriporites*, *Scabratriporites*, *Proteacidites*, *Cupanieidites*, *Syncolpites*, *Auriculiidites*, *Buttinia* and *Retidiporites*, and the spore *genera Zlivisporis and*

Ariadnaesporites. A southern hemisphere *Proteacidites/ Nothofagidites* (*Nothofagidites*) Province is defined by the pollen genus *Nothofagidites*, of the southern beech, *Nothofagus*, and the pollen genera *Beaupreadites* and *Proteacidites* of the Proteaceae.

Frederiksen (1987) identified a fifth Late Cretaceous floral province: the Continental Margin Province, lying between 35° N and 50° N present latitude along the western coast of North America and distinguished by rich assemblages of Proteaceae pollen taxa including *Beaupreadites elegansiformis* and fern spore genera including *Appendicisporites*. The presence of the Proteaceae pollen genera indicates a humid subtropical to temperate climate (Srivastava, 1970).

Recently, Herngreen *et al.* (1996) identified the Khantanga-Lena Subprovince, a subdivision of the *Aquilapollenites* Province that spans northern Far East Russia, and described it as a separate paleofloral unit. Their determination is based on the presence of *Azonia recta* and "the absence of subtropical pollen, and poorer, less diverse angiosperm palynofloras." They also define a seventh Late Cretaceous province, the *Schizaeoisporites* Province in southeast Asia, based on the common to abundant presence of spores of the genera *Schizaeoisporites* and

Cicatricososporites, the abundant presence of *Ephedripites* and *Classopollis* pollen grains, and the moderately common pollen genera *Oculopollis* and *Trudopollis.* Southern Africa is set apart as "unknown" because information on palynomorphs of Late Cretaceous age is lacking, and Central America is designated as "unknown" because it did not exist during the Late Cretaceous (Herngreen *et al.*, 1996).

Geographic locations and geologic environments of Late Cretaceous paleofloras of Alaska

To date, paleofloras of Cretaceous Alaska have been considered part of the undifferentiated Western or *Aquilapollenites* Province. The most important Campanian-Maastrichtian paleofloras found in Alaska are from the Prince Creek Formation of northern Alaska, the Lower Cantwell Formation of interior Alaska, and the Matanuska, Chignik and Kaguyak formations of southcentral Alaska. Northern Alaskan paleofloras **(Table 1)** share genera with the paleofloras of the Khatanga-Lena Subprovince of Far East Russia and the *Aquilapollenites* province of western North America. Dispersal corridors between these regions have never been well defined. However, Stanley (1970) states that stratigraphic and geographic distribution of triprojectate pollen of the *Aquilapollenites* Group stretched

Table 1

Representative pollen genera of major pollen groups of the *Aquilapollenites* Province
(Wiggins, 1976; Takahashi and Shimono, 1982; Frederiksen, 1987; Traverse, 1988)

***Aquilapollenites* Pollen Group:**

Triprojectate form genera:

Aquilapollenites	*Mancicorpus*
Triprojectus	*Integricorpus*
Hemicorpus	*Bratzevaea*

Oculate form genera:

Wodehouseia	*Azonia*

***Callistopollenites* Pollen Group:**

Callistopollenites	*Cercidiphyllites*
Cranwellia	*Erdtmanipollis*
Grewipollenites	*Kurtzipites*
Loranthacites	*Pulcheripollenites*
Senipites	

Normapolles Pollen Group

Trudopollis	*Extratriporopollenites*
Oculopollis	*Plicapollis*

Proteaceae Pollen Group

Proteacidites	*Beaupreadites*

***Podocarpidites* Pollen Group**

all *Podocarpidites* species

TCT Pollen Group

Taxodiaceae
Cupressaceae
Taxaceae

from western Siberia eastward to Alaska during the Coniacian and Campanian and subsequently advanced into the northwest Great Plains and the Rocky Mountain areas of North America by the Maastrichtian. Norris *et al.* (1975) concur with Stanley, but they could not determine whether the floras were dispersed along the "marginal lands broadly encircling the proto-Arctic ocean basin" or over a dry land Barents Shelf corridor to North America. Frederiksen (1987) and many others (Tschudy, 1969; Srivastava, 1970; McIntyre, 1974b; Norris *et al.*, 1975; Frederiksen, 1986; Frederiksen and Schindler, 1987) have further reported that the maximum diversities of pollen taxa in the *Aquilapollenites* and *Callistopollenites* Groups, recognized in Campanian-Maastrichtian paleofloral assemblages from western Canada and northern Alaska, decrease rapidly south of Montana and South Dakota, regions far from the center of origin in western Siberia (Vakhrameev, 1964, 1971, 1972, 1976, 1991; Vakhrameev *et al.*, 1970).

The most-studied Alaskan paleofloras in the last half century are those which have been found in the Arctic Alaska Terrane. Comparison of the Albian Kuk River and Meade River paleomicrofloral assemblages of the western Arctic to the Coniacian-Campanian Tuluvak Tongue paleomicrofloral Plain) **(Fig. 2)**, suggests that palynological differences

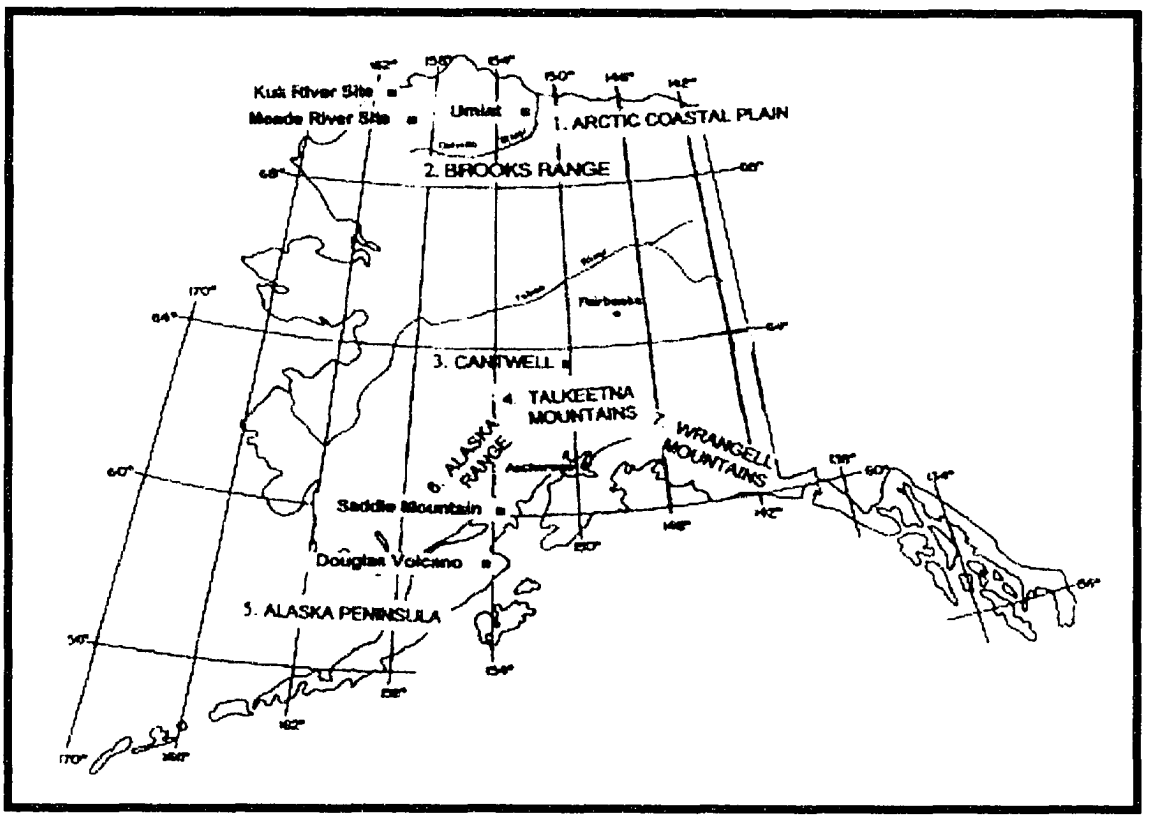

Fig. 2. Map of Alaska. 1. The Arctic Coastal Plain (North Slope) including Umiat, Colville River, Kuk River and Meade River sites; 2. Brooks Range; 3. Cantwell; 4. Talkeetna Mountains; 5. Alaska Peninsula including Douglas Volcano and Saddle Mountain; 6. Alaska Range; and 7. Wrangell Mountains (modified from Pasch and May, 1995).

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assemblages of the Prince Creek Formation (Arctic Coastal within northern Alaska reflect paleolatitudinal differences (Stanley, 1967). Palynofloral assemblages from exposures of the Corwin Formation along the Kuk Inlet and Meade River of the northwestern Arctic Coastal Plain were very similar to upper Lower Cretaceous palynofloras from Siberia and western Canada, whereas pollen grains and spores from the Tuluvak

tongue of the Prince Creek Formation, **(Fig. 2)** central Arctic Coastal Plain, are more similar to central European paleofloras which first appeared in Europe during the Lower Tertiary (Stanley, 1967). Deposits of the Tuluvak Tongue are dated as Coniacian to Campanian using invertebrate fossils (Jones and Gryc, 1960) but none of the palynomorphs Stanley (1967) found permitted precision age dating. These trends suggest that the Siberian paleoflora dispersed toward western and Arctic Alaska during the Early Cretaceous, reached western Alaska by the early Late Cretaceous and advanced further eastward by the Late Cretaceous, thus contributing to the Prince Creek paleoflora in the central Arctic Coastal Plain. It is easy to speculate that the Prince Creek paleoflora was then dispersed eastward along the Arctic coastal margin to Central Europe **(Fig. 2)**.

Smiley (1967) makes comparisons between the Cretaceous Corwin Formation and Prince Creek Formation floras and living plant taxa, relates them to climates, and shows that living relatives of Albian plants from northern Alaska are now confined to humid warm climates at latitudes south of about 30° N; modern relatives of later Cretaceous plants are confined to humid temperate climates at latitudes of about 35°-45° N. This shows a cooling of climates over time (Smiley, 1967).

Upper Cretaceous continental margins now incorporated into land masses of the Russian Far East, and the North American west coast are all part of the *Aquilapollenites* Province which extends from northern Japan and the Russian Far East to Alaska, coastal northwest Canada, Washington and California (Brenner, 1963; Srivastava, 1978, 1981; Wolfe, 1987; Spicer, 1987; Spicer *et al.*, 1987; Frederiksen *et al.*, 1987; Traverse, 1988; Frederiksen, 1989, 1991; Vakhrameev, 1991) **(Fig. 1)**. However, during the Mesozoic, the tectonic terranes that comprise Alaska were spread over such vast distances that it is difficult to believe that the same climate prevailed on all these terranes. During the Campanian and Maastrichtian, Alaskan terranes may have extended from 85° N to the equator (Stone, Pers. comm., 1995). By comparison, present day Alaska, excluding the panhandle, lies between 61° N and 71° N.

The Arctic Alaska Terrane underlies all of the North Slope of Alaska and most of the Brooks Range (Newman *et al.*, 1977; Fujita and Newberry, 1982; Mull, 1982; Moore *et al.*, 1994). Opening of the Canadian Basin in the Arctic Ocean at about 190-185 M.y. (Jurassic) **(Fig. 3)** contributed to folding of northern coastal Alaska (Grantz and May, 1983). During the Jurassic-Cretaceous, uplift of the Brooks Range occurred in two phases, creating a physiographic barrier

between the northern coast and the interior of Alaska (Moore *et al.*, 1994). The older Brookian phase, which probably occurred during the Middle Jurassic and Early Cretaceous, resulted in ductile deformation and metamorphism of the southern Brooks Range and caused large thrust sheets to advance northward.

The younger Brookian orogenic phase included three deformational events. This entire phase is regarded by Grantz *et al.* (1981) as Late Cretaceous (Campanian-Maastrichtian) or Tertiary. Mull (1979, 1985), however, believes the phase began as early as Albian, 113.0 to 97.5 M.y. (Obradovich, 1993), or earlier. The three deformational events include northward displacement of the northern central foothills of the Brooks Range, formation of an east-directed fold belt under the Chukchi Sea, and uplift of the eastern Brooks Range (Moore *et al.*, 1994). This last event, known as the Romanzof uplift, occurred during the Late Cretaceous or Tertiary (Grantz *et al.*, 1983, 1987). At the same time, subduction of the Kula and Pacific Plates beneath the southcentral margin caused compression of southern Alaska (Hudson, 1979, 1983; Wallace and Engebretson, 1984). Northward motion of the southern portion of Alaska, caused by subduction, may have altered paleolatitudes (Moore, 1973b).

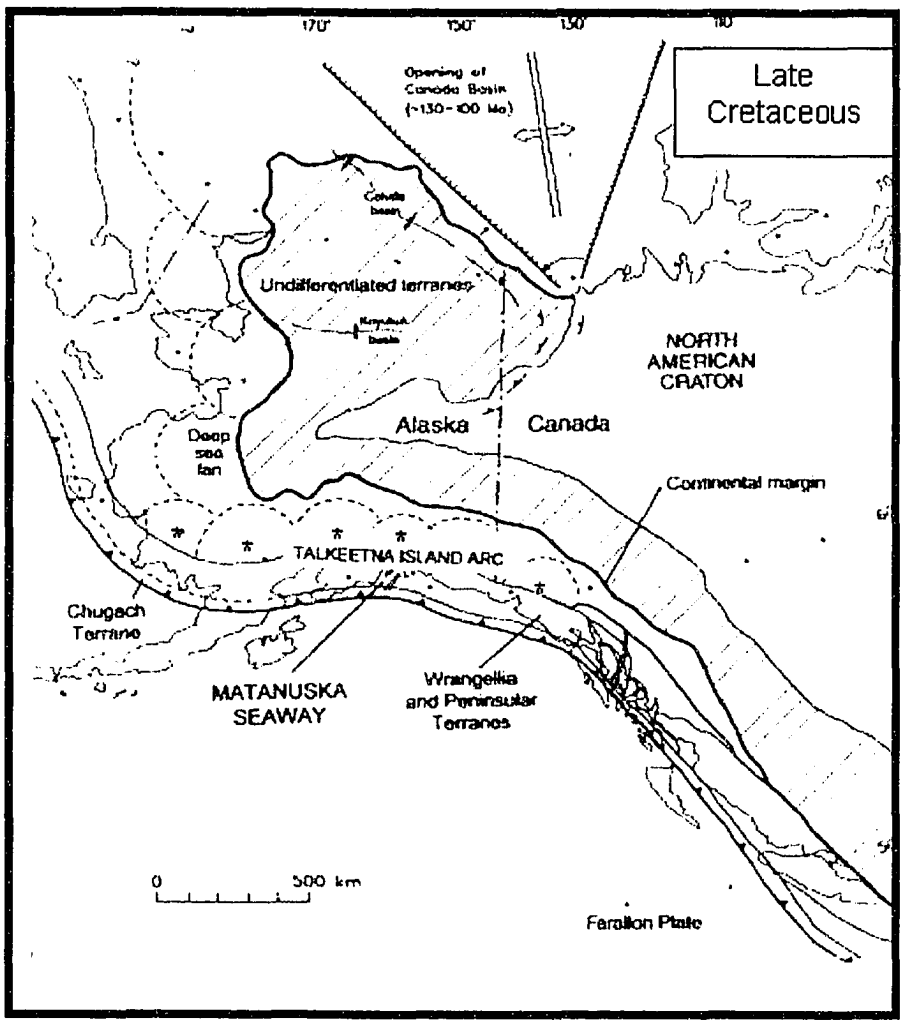

Fig. 3. Location of Matanuska Seaway, Late Cretaceous. Paleogeography of Late Cretaceous Alaska showing a possible configuration of the Wrangellia, Peninsular, and Chugach Terranes with locations of Talkeetna Island Arc volcanoes **(*)** within the Matanuska Seaway (modified from Plafker and Berg, 1994; Pasch and May, 1995).

In addition, strong evidence suggests that the Talkeetna Island Arc system, "consisting of Jurassic volcanic and volcaniclastic sedimentary rocks of dominantly andesitic to dacitic composition" (Burns *et al.*, 1991), was

accreted to the southern margin of Alaska during the Late Cretaceous and Early Tertiary (Wilson and Weber, 1994). As this system docked, another physiographic barrier, the Talkeetna Mountain Range, was created between interior and southcentral Alaska (Hudson, 1979, 1983) **(Fig. 2)**.

Remnants of many extinct Mesozoic volcanoes are exposed in outcrop throughout the Talkeetna Mountain Range, including Sheep Mountain **(Fig. 4)** and Mount Wickersham, which are visible along the Glenn Highway at Mile 114, approximately 60 miles northeast of Palmer, Alaska **(Map in pocket)**. The presence of these extinct volcanoes suggests the potential for the discovery of local volcanic recovery floras (Myers and Fisher, 1994; Myers, 1996) within the Matanuska Formation in the Talkeetna Mountains **(Map in Pocket)**. Local volcanic recovery floras are identified by two characteristics: 1.) florules, single horizons or laminae which contain fossil ferns "mixed with a high percentage of juvenile volcanic detritus" (Myers, 1996); overlain by 2.) a sequence of microfloras or macrofloras showing several stages of recovery. In the first stage of recovery, the floral community is dominated by low-diversity vegetation of "weedy" trees and vines. This "weedy" flora is gradually replaced with a pre-eruptive vegetation (Myers and Fisher, 1994; Myers, 1996). Myers (1993) reports seeing

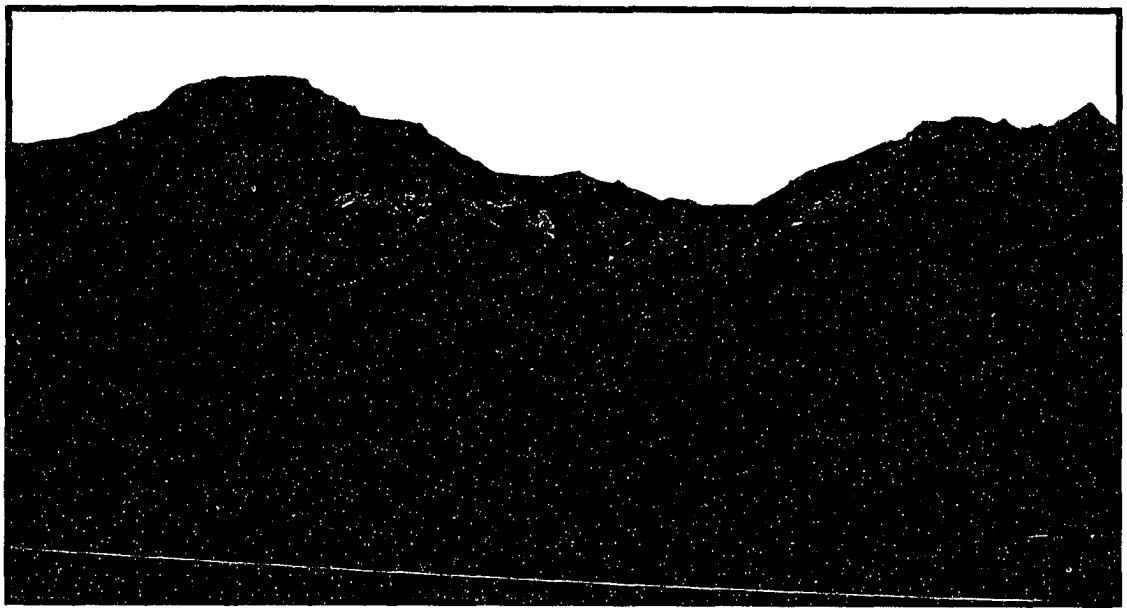

Fig. 4. Sheep Mountain, extinct Talkeetna Island Arc volcano. This outcrop reveals remnants of an extinct Mesozoic volcano at Mile 114 of the Glenn Highway at the northern margin of Matanuska Valley, Alaska (photo by S. Reid).

the entire sequence repeated four to six times in a 1-meter-thick sequence of rock in the Cedarville floras of northeast California.

The Matanuska paleoflora, described herein, is found in Campanian-Maastrichtian continental margin deposits (Fisher and Magoon, 1978) of the upper Alaska Peninsula on the west side of Cook Inlet, and in the Talkeetna Mountains, north of Anchorage. These sites are located on the North Pacific Rim between the Russian Far East and the continental margin of the 48 contiguous United States. The paleofloras of the

Chignik (Hollick, 1930; Wiggins, 1976, 1988) and Kaguyak Formations (Magoon *et al.*, 1980), Alaska Peninsula, are combined with the Matanuska Formation paleoflora in this report because these formations contain coeval Maastrichtian floras from the southcentral Alaska continental margin.

Maastrichtian coastal paleofloras were found on the Alaska Peninsula **(Fig. 2)** in the Chignik (Hollick, 1930) and Kaguyak Formations (Fisher and Magoon, 1978). Maastrichtian species of *Aquilapollenites* and numerous oculate pollen species of *Wodehouseia, Azonia,* including several new species, have been recovered from the Chignik Formation (Wiggins, 1976) **(Fig. 2)**. In addition, *Mancicorpus anchoriforme,* a pollen species belonging to the *Aquilapollenites* Group, is locally abundant on the Alaska Peninsula (Wiggins, 1976). The presence of *M. anchoriforme,* which is found on the margins of the Bearpaw Sea in Alberta, Canada, suggests a humid subtropical climate (Srivastava, 1972). Maastrichtian pollen species of the *Aquilapollenites, Callistopollenites* and *Proteacidites* Groups have been recovered from nonmarine sedimentary deposits of the Kaguyak Formation on the upper Alaska Peninsula **(Fig. 2)** around Douglas Volcano and at Saddle Mountain (Magoon *et al.*, 1980). Outcrops of the Kaguyak Formation are found just north of outcrops of the Chignik

Formation. These formations are coeval with the Matanuska Formation and appear to represent the continental margin west of the accreted Talkeetna volcanic island arc system. Kryshtofovich (1918) and Vakhrameev (1991) noted that abundant fossils of the cycad genus *Nilssonia* are found in Late Cretaceous rocks primarily along the two coasts of the Pacific Ocean, including Sakhalin, northeast U.S.S.R., Japan, Alaska and western Canada.

The Cantwell paleoflora, from the Lower Cantwell Formation in the central region of the Alaska Range, is present in outcrops at two separate regional locations: Polychrome Pass inside Denali National Park and Preserve (Sweet, 1994a), and numerous sites in the Healy Quadrangle outside of Denali National Park Preserve (Sweet, 1994b). During the Late Cretaceous, stream drainage from the interior of Alaska emptied southward into the Matanuska Seaway **(Fig. 3)** depositing sediment which formed the Lower Cantwell Formation. The Lower Cantwell paleomicroflora extracted from the Polychrome Pass outcrop is composed predominantly of pollen species of the *Aquilapollenites* and *Callistopollenites* Groups, with an abundance of gymnosperm pollen species of the Taxaceae, Cupressaceae and Taxodiaceae (TCT) in several florules (Sweet, 1994a). The Cantwell paleoflora lacks the fern genus *Appendicisporites*

characteristic of the Continental Margin Province and the pollen genus *Proteacidites* (Frederiksen, 1987), although several grains of one species of *Siberiapollis*, which is morphologically very similar to Proteaceae, are present (Sweet, 1994a). The Cantwell paleoflora also lacks the *Aquilapollenites* Group pollen species *Mancicorpus anchoriforme*, which is a characteristic constituent of coastal paleofloras (Wiggins, 1976; Srivastava, 1972).

Reconstructing paleoclimate, paleolatitude and geologic age

Nichols and Sweet (1993) and Frederiksen (1987) use paleofloras to reconstruct the paleoclimate, paleolatitude, and geologic age of Cretaceous North America. Nichols and Sweet (1993) use first occurrence data of selected pollen taxa to define regional biostratigraphic units. Their analyses demonstrate that, from the Albian to the Maastrichtian stages, five distinct assemblages succeed one another along the margins of the Cretaceous Western Interior Seaway (CWIS), which extended from Yukon to New Mexico **(Fig. 5)**. From oldest to youngest, these assemblages are dominated by the following pollen types:

1.) Tricolporate-Obligate Tetrads (Albian to Cenomanian)

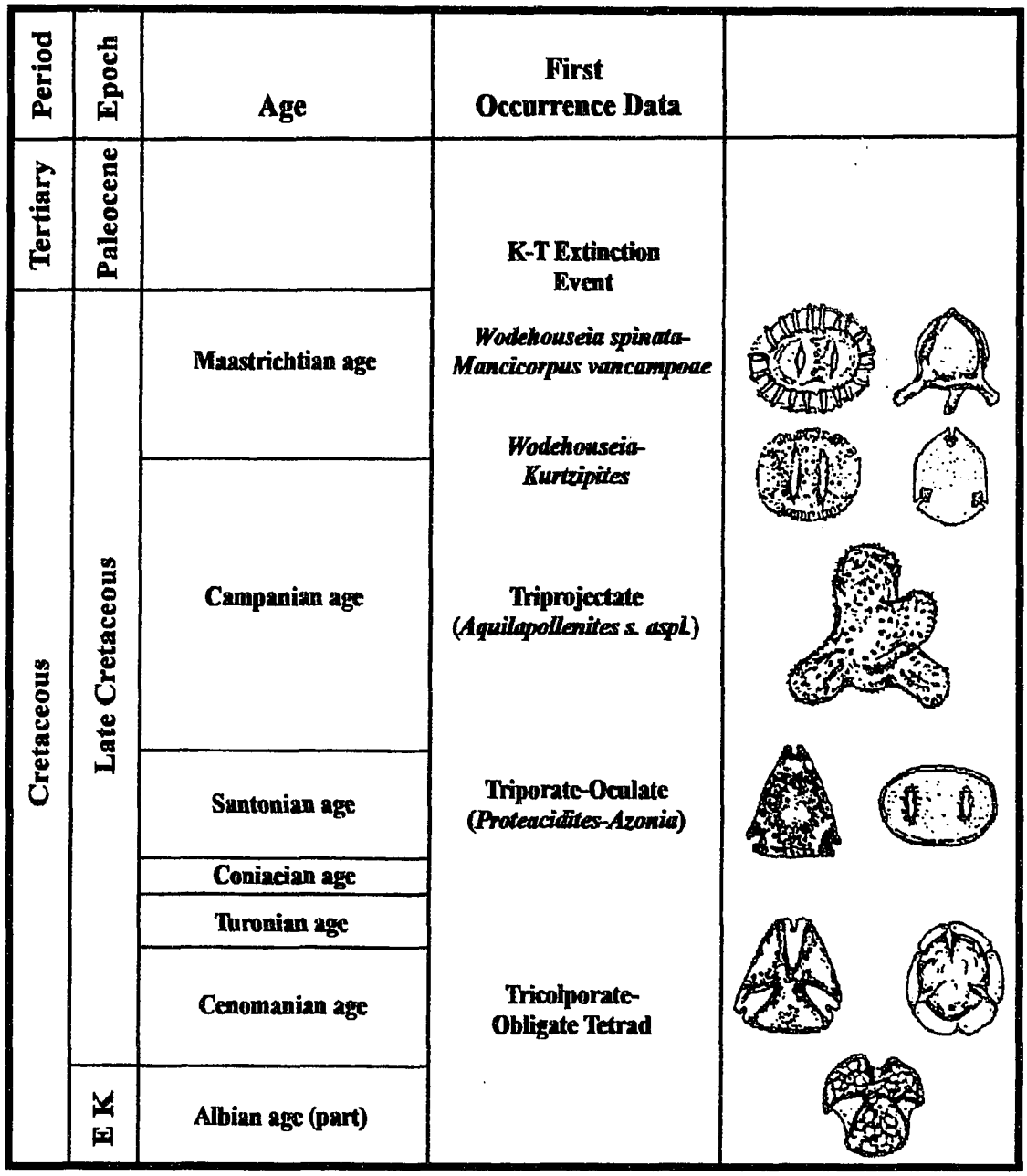

Fig. 5. Palynologic first occurrence data for the non-marine Upper Cretaceous of the Western Interior Basin. First occurrences of morphologic forms and individual taxa shown here permit broad regional correlations between the Yukon Territory and New Mexico (modified from Nichols and Sweet, 1993).

2.) Triporate-Oculate pollen of the genera *Proteacidites* and *Azonia* (Turonian to the Santonian)

3.) Triprojectate pollen of the *Aquilapollenites* Group (Campanian)

4.) *Wodehouseia* and *Kurtzipites* (Campanian-Maastrichtian boundary)

5.) *Wodehousia spinata* and *Mancicorpus vancampoae* during the upper Maastrichtian.

Geographically, certain taxa from these assemblages are characteristic of the northern, central or southern regions of the CWIS **(Table 2)**. Therefore, these taxa can be used to reconstruct paleolatitude.

The Late Cretaceous Continental Margin Province is located on the west coast of North America, between 35° N and 50° N present latitude (36° N to 52° N paleolatitude) (Smith *et al.*, 1981; Frederiksen, 1987). The Continental Margin Paleoflora is dominated by Proteaceae Group pollen genera and diverse fern spore species. The palynological composition of this province is based on descriptions of the La Panza paleomicroflora, found near Santa Margarita in central California (Frederiksen, 1987), and the Upper Cretaceous (Campanian-Maastrichtian) Nanaimo paleoflora, found on Vancouver Island, British Columbia (Crickmay and Pocock, 1963). The Nanaimo paleoflora contains the same

Table 2
Geographically endemic pollen taxa of the North, Central, and South CWIS
(modified from Nichols and Sweet, 1993)

Series	North (N) >75° N	Central (C) 60-75° N	South (S) <60° N
Uppermost Maastrichtian	**(N, C)** *Wodehouseia spinata* Stanley 1961	**(C)** *Mancicorpus vancampoae* Srivastava 1968	
Upper Maastrichtian	**(N)** *Wodehouseia quadrispina* Wiggins 1976 **(N)** *Wodehouseia octaspina* Wiggins 1976 **(N)** *Aquilapollenites parallelus* Tschudy 1969 **(N)** *Aquilapollenites reticulates* (Mchedlishvili) Tschudy and Leopold 1971 **(N)** *Triprojectus unicus* (Chlonova) Mchedlishvili 1961 **(N)** *Triprojectus magnus* (Mchedlishvili) Stanley 1970	**(C)** *Mancicorpus rostratus* Srivastava 1968 **(C, S)** *Tricolpites microreticulatus* Belsky, Boltenhagen and Potonié 1965	**(S)** *Tilia wodehousei* Anderson 1960 **(S)** *Arecipites* spp. Wodehouse 1933 **(S)** *Liliacidites complexus* (Stanley) Leffingwell 1971
Campanian-Maastrichtian	**(N, C)** *Wodehouseia* spp. Stanley 1961		
Mid-Campanian	**(N, C)** *Azonia* spp. Samoilovitch 1961 **(N, C)** *Expressipollis* spp. Chlonova 1961	**(C)** *Aquilapollenites regidus* Tschudy and Leopold 1971 **(C, S)** Proteaceae Cookson 1950	

angiosperm, gymnosperm and sporophyte elements that Frederiksen (1987) found in the La Panza paleoflora. The ornamented fern spore *Appendicisporites* **(Fig. 6)** and the Proteaceae Group pollen species *Beaupreadites elegansiformis* occur "in almost every sample" in the Nanaimo paleoflora (Crickmay and Pocock, 1963).

The presence of similar Proteaceae pollen genera and an abundance of fern spore genera, including one specimen of *Appendicisporites*, in the Matanuska Formation allies the Matanuska Paleoflora with Frederiksen's (1987) Late Cretaceous Continental Margin province. The presence of several Proteaceae pollen genera combined with a large number of *Aquilapollenites* Group pollen indicates that the Matanuska flora is a northern transitional continental margin flora bridging Pacific Rim floras of the Russian Far East and the Continental Margin floras of British Columbia and central California.

Comparison of the three Alaskan Campanian-Maastrichtian paleofloras

In Arctic Alaska, the Prince Creek paleoflora is currently considered part of the *Aquilapollenites* Province, which spanned the coast of the paleo-Arctic Ocean (Stanley, 1970;

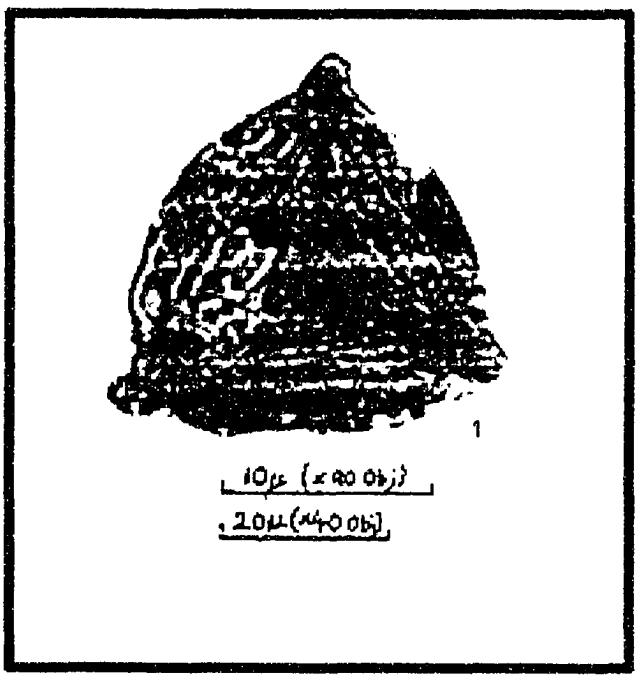

Fig.6. Ornamented *Appendicisporites* fern spore. Discovered in the paleoflora within the Nanaimo Series, Crickmay and Pocock (1963) found this spore species and the Proteaceae pollen *Beaupreadites elegansiformis* Cookson to be present "in almost every sample" (modified from Crickmay and Pocock, 1963).

Frederiksen, 1987; Frederiksen *et al.*, 1987; Norris *et al.*, 1975). Wiggins (1976) reports the rare occurrence of *M. anchoriforme* in the Arctic paleoflora, which Srivastava (1972) considers to be a subtropical, coastal pollen species. The Prince Creek flora contains fewer pollen species of the Proteaceae and *Aquilapollenites* Groups than the Matanuska, Chignik, and Kaguyak paleofloras of southcentral Alaska. This suggests a cooler climate existed in northern Alaska.

The Cantwell paleoflora differs from the Arctic and southcentral paleofloras (Sweet, 1994a, 1994b) in that it contains no Proteaceae Group pollen and very few species of fern spores. However, Sweet (1994a) does report the presence of one species of *Siberiapollis* pollen, which is morphologically similar to Proteaceae pollen. The presence of one specimen of an *Ephedra* pollen genus suggests a warm dry climate (Sweet, 1994a), but one florule contains abundant Taxaceae, Cupressaceae, and Taxodiaceae pollen indicating that a warm, humid climate prevailed, if only briefly.

Alaskan paleofloras **(Table 1)** share genera with neighboring regions along the North Pacific Rim. Continental margins to the southeast (British Columbia, Washington and California) and to the west (Russian Far East and northern Japan) contain paleofloras dominated by pollen species of the Proteaceae and *Aquilapollenites* Groups and abundant fern spores (Samoilovich, 1967; Takahashi, 1970; Miki, 1977; Herngreen and Chlonova, 1981; Frederiksen, 1987; Frederiksen *et al.*, 1987; Markevitch, 1994; Ridgway *et al.*, 1997). The diversity and abundance of fern spore species is similar throughout all the North Pacific Rim paleofloras.

The Matanuska paleoflora contains more Proteaceae pollen species than all the other Alaskan Campanian-

Maastrichtian paleofloras mentioned herein. The different abundances of Proteaceae and *Aquilapollenites* Group pollen species in paleofloras from the west, central and eastern margins of the North Pacific Rim suggest a range of humid to dry, and tropical to subtropical climates. From north to south, the number of triprojectate species within the *Aquilapollenites* Group recovered from Cretaceous Alaskan floras increases from 21 in the Colville Group floras to 24 in the Matanuska paleoflora, including the Chignik and Kaguyak paleofloras. Genera of Proteaceae Group pollen also increase southward from three in the Colville Group floras to eight in the Matanuska flora. The intermediate Cantwell flora of interior Alaska contains 21 species of *Aquilapollenites* Group pollen and no Proteaceae Group pollen. The north to south increase in diversity of Proteaceae Group and *Aquilapollenites* Group pollen, in conjunction with the appearance of the fern spore genus *Appendicisporites* in the southcentral Matanuska flora, are believed to represent a transition from a cool, Arctic Continental Margin northern paleoclimate wherein the coastal *M. anchoriforme* is rare, to a warm dry interior climate, and a warm humid southcentral climate wherein *M. anchoriforme* is very abundant. Thus, the Alaska paleofloras exhibit a gradational transition between a previously unrecognized

Arctic Continental Margin paleoflora along the Arctic Coastal Plain to floras of the *Aquilapollenites* Province in the interior of Alaska and floras characteristic of a Northern Continental Margin Floral Province in southcentral Alaska.

Based on paleo-geographic location and paleofloral constituents, the Matanuska paleoflora represents a coastal dispersal corridor where elements of eastern and western continental margin paleofloras mixed. The Matanuska paleoflora is enriched in species as a result of paleofloral interchange between the Russian Far East and western North America.

Sedimentary facies of the Matanuska Formation

The Matanuska Formation is a segment of an extensive Cretaceous forearc basin. Geographically, it is a curvilinear unit inboard of, and generally parallel to, the Gulf of Alaska. It has most recently been described as a marine onlap sequence of the Wrangellia Composite Terrane (WTC), which includes the Peninsular Terrane, the Prince Alexander Terrane and the Wrangellia Terrane (Nokleberg *et al.*, 1994a) **(Fig. 7)**. The Matanuska Formation is an important onlap sequence because it constrains the time of

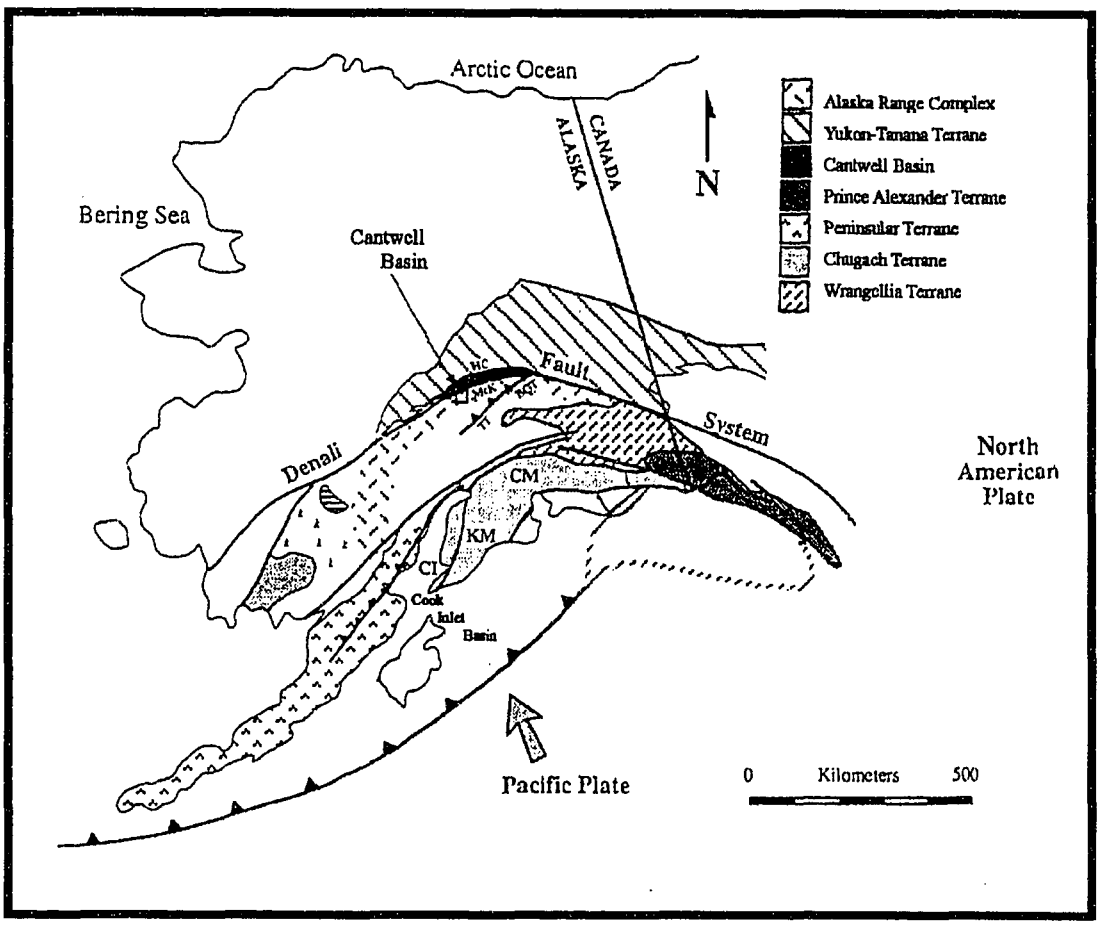

Fig. 7. General terrane map of southcentral Alaska. The Peninsular Terrane, Wrangellia Terrane and Prince Alexander Terrane comprise the Wrangellia Composite Terrane of Nokleberg *et al.* (1994a); CM, Chugach Mountains; KM, Kenai Mountains (modified from Fitzgerald *et al.*, 1995).

amalgamation of the Peninsular and Wrangellia Terranes (Nokleberg *et al.*, 1994b). It is also a major component of the modern Cook Inlet Basin, which contains much of Alaska's hydrocarbon resources **(Fig. 7)**.

The Matanuska Formation crops out in the Talkeetna Mountains (**Figs. 8 and 9**). To the southeast, it abuts the southern flanks of the Wrangell Mountains that edge the Copper River Basin. The K_2 and K_3 members of the Matanuska Formation (Jones and Berg, 1964) extend from the eastern edge of the Talkeetna Mountains southeastward into Prince William Sound. The K_2 unit crops out on MacColl Ridge, McCarthy A-4 quadrangle. Lithology of the Coniacian to Campanian age K_2 unit consists of black shale and siltstone, and fine-grained sandstone containing calcareous concretions. The K_2 lies unconformably over the K_1 unit. The upper part of unit K_2 contains a limited fauna of Campanian age, including *Eupachydiscus haradai* (Jimbo) and *Inoceramus schmidti* Michael. Unit K_3, the uppermost Cretaceous formation, also crops out on MacColl Ridge, McCarthy A-4 quadrangle, and is composed of interbedded sandstone, conglomerate and gray siltstone and shale. It lies comformably over the K_2 unit (Jones and Berg, 1964). Deposition of the Matanuska Formation was contemporaneous with the existence of the epeiric Cretaceous Western Interior Seaway (CWIS) which extended from the Arctic Ocean to the proto-Gulf of Mexico during Albian and Maastrichtian time (Parrish *et al.*, 1984; Stott *et al.*, 1993; Nichols and Sweet, 1993) (**Fig. 10**). However, the Matanuska Seaway

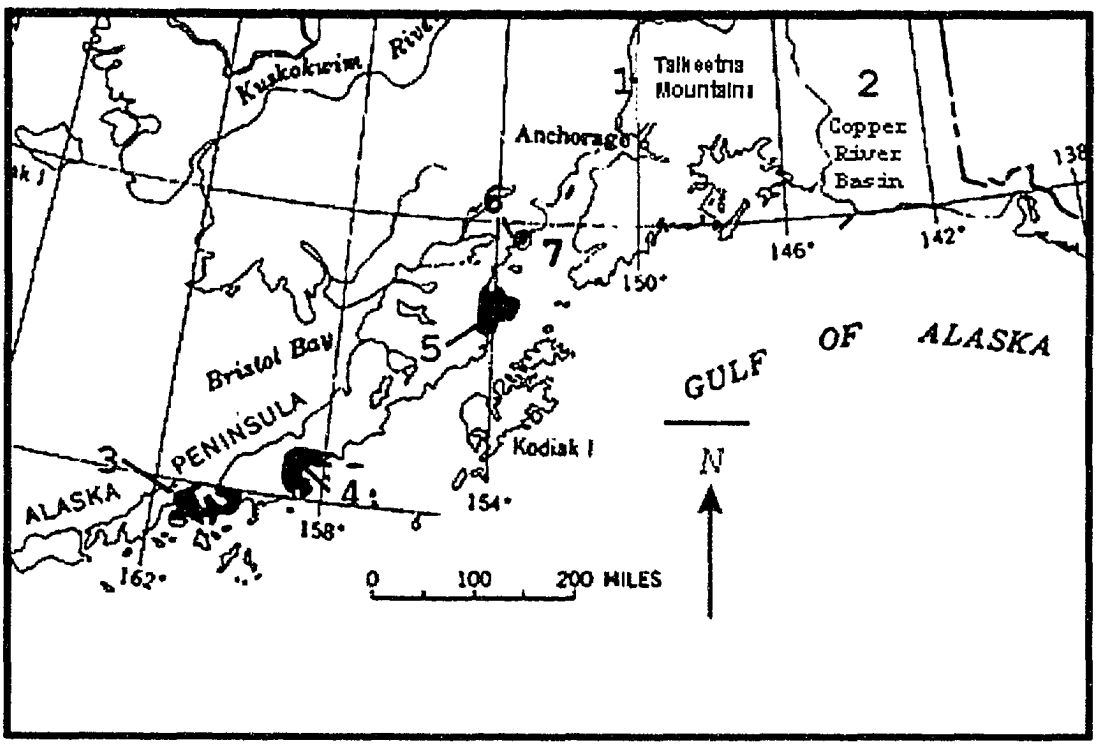

Fig. 8. Location map of the Matanuska Formation and its lateral equivalents. 1) Talkeetna Mountains and Matanuska Formation; 2) Copper River Basin, Wrangell Mountains, and K_2 and K_3 members of the Matanuska Formation; 3) Herendeen Bay, Coal Valley Member of Chignik Formation; 4) Chignik Bay, Chignik Formation; 5) Kamishak Hills, Douglas Volcano and marine unit of Kaguyak Formation; 6) Saddle Mountain and nonmarine unit of Kaguyak Formation; and 7) Cook Inlet Basin (modified from Grantz and Jones, 1960; Jones and Berg, 1964; Kirschner and Lyon, 1973; Fisher and Magoon, 1978; Magoon *et al.*, 1980; and Merritt, 1987).

probably was not connected to the CWIS. It was located south of, and parallel to, the Alaska Range. The modern Cook Inlet is a reduced remnant of the Cretaceous Matanuska Seaway (Payne, 1955) **(Fig. 7)**.

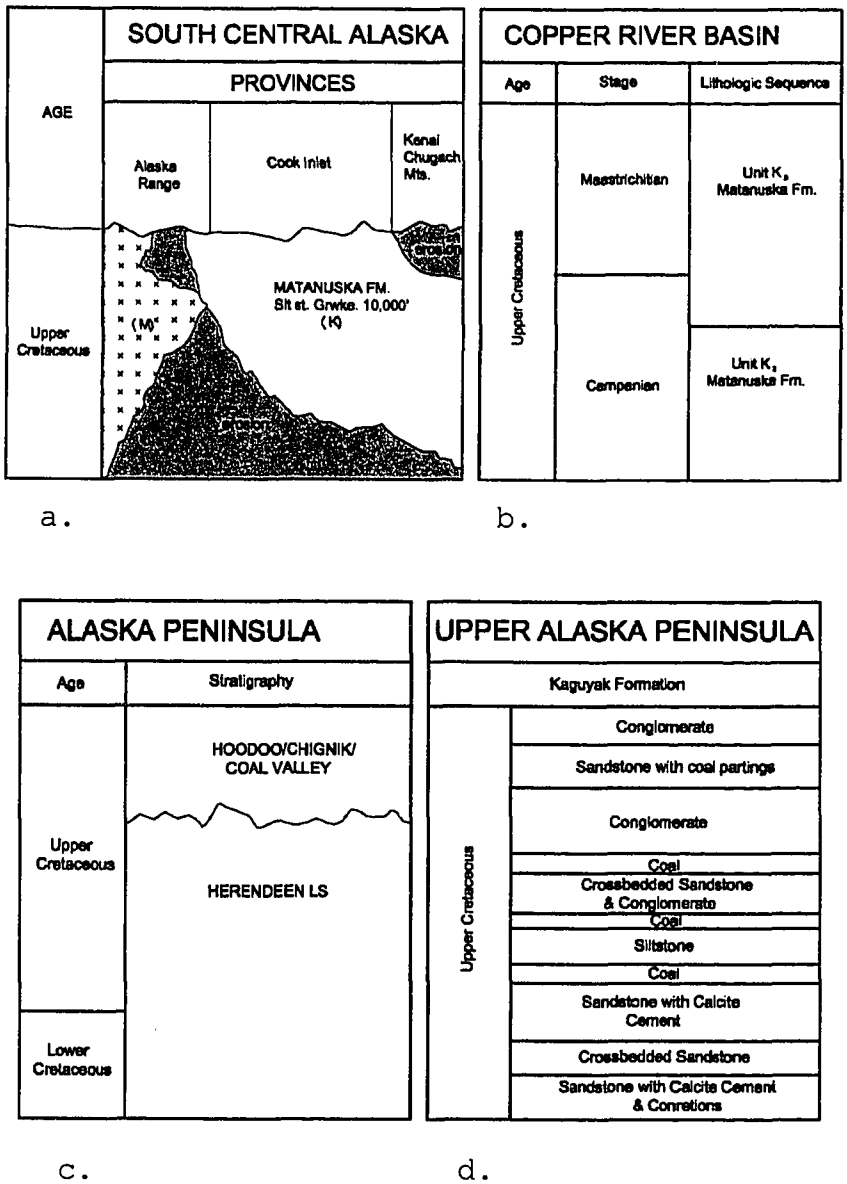

Fig 9. Campanian-Maastrichtian stratigraphy of southcentral Alaska. Marine and non-marine Campanian-Maastrichtian stratigraphy of southcentral Alaska: a. the Matanuska Formation in the Cook Inlet Basin, Talkeetna Mountains (Kirschner and Lyon, 1973); b. the Matanuska Formation in the Copper River Basin, Talkeetna Mountains (Jones and Berg, 1964); c. the laterally equivalent Chignik and Hoodoo Formations on the Alaska Peninsula (Fisher and Magoon, 1978; and Merritt, 1987); and d. Kaguyak Formation on the western margin of Cook Inlet (Magoon *et al.*, 1980).

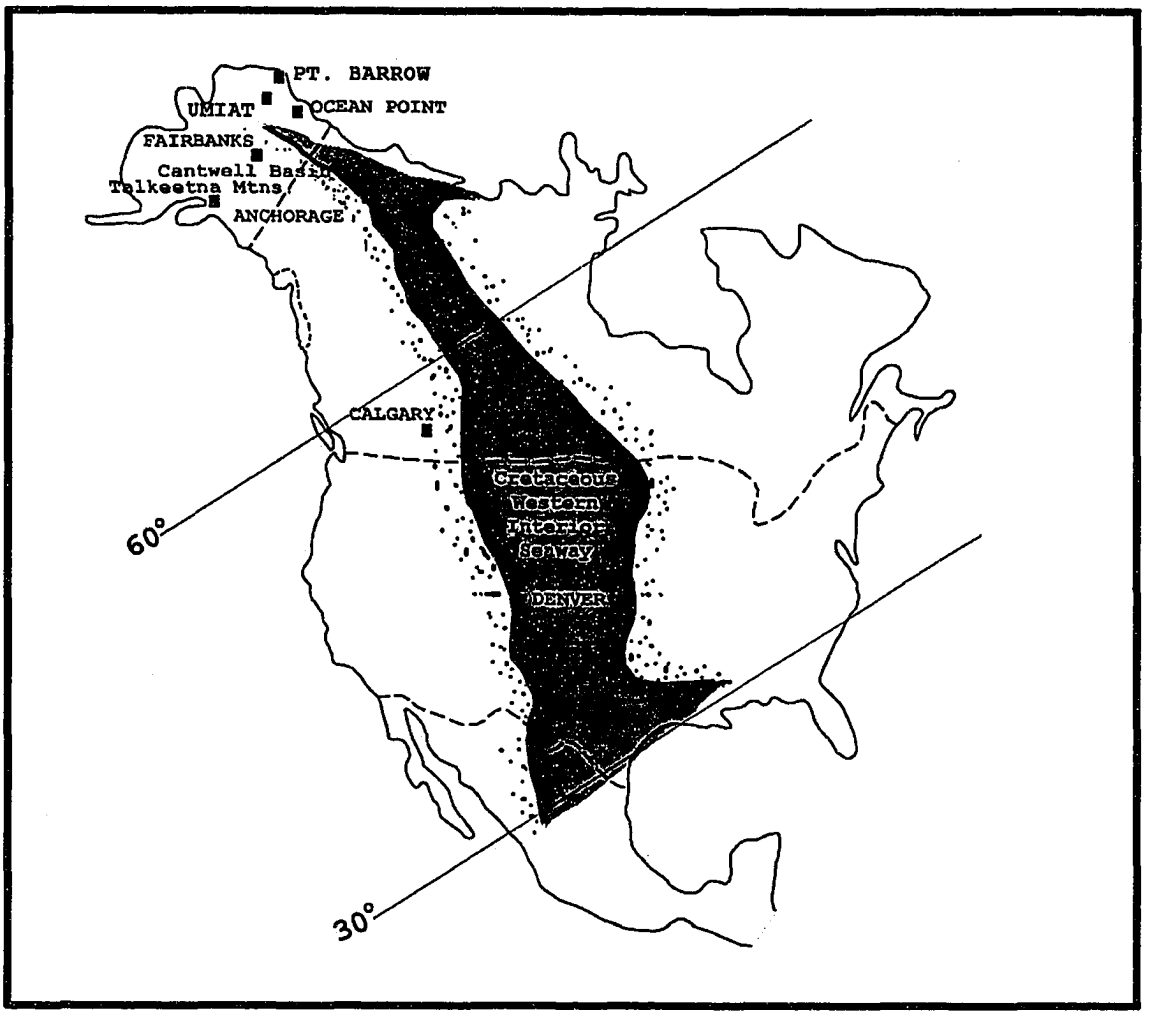

Fig. 10. General map of the Cretaceous Western Interior Seaway. The CWIS basin and its position on the North American craton (modified from Parrish *et al.*, 1984).

Three coeval formations, the Chignik, Hoodoo, and Kaguyak, are exposed in forearc basin deposits along the western margin of Cook Inlet and south along the Alaska Peninsula **(Figs. 8 and 9)**. Outcrops include the nonmarine

Coal Valley Member of the Chignik Formation, as well as the marine inner neritic Chignik Formation and outer neritic-bathyal Hoodoo Formation (Mancini *et al.*, 1978) that crop out at Chignik Bay and Pavlof Bay, respectively.

The Kaguyak Formation is laterally equivalent to the Matanuska Formation. Both formations were deposited on the continental shelf of southcentral Alaska by a transgressing sea during the Maastrichtian (Fisher and Magoon, 1978). The marine unit of the Kaguyak Formation crops out in the Kamishak Hills of the upper Alaska Peninsula, while its only nonmarine unit is exposed at Saddle Mountain, northwest of Chinitna Bay **(Figs. 8 and 9)**. The westward extension of the Cretaceous forearc basin, which includes the Matanuska, Chignik, Hoodoo, and Kaguyak formations, appears to parallel the Bering Sea shelf, cropping out in the Koryak Mountains of the Russian Far East (Pratt *et al.*, 1972; Moore, 1973b, 1974; Marlow *et al.*, 1976, 1979, 1983a, 1983b; Fujita and Newberry, 1983; Cooper *et al.*, 1987; Stone, 1988).

Two important problems

The Peninsular Terrane, a component of the Wrangellia Composite Terrane, has been placed at several different paleolatitudes during the Late Cretaceous and assigned conflicting dates for docking with North America (Hillhouse,

1987; Nokleberg *et al.*, 1994a; Nokleberg *et al.*, 1994b). The Matanuska Formation is a component of the Peninsular Terrane which contains Campanian-Maastrichtian paleofloras. Similarities between these floras and floras from the margins of the CWIS (Nichols and Sweet, 1993) will be used to test previous assertions regarding paleolatitudes.

Fossiliferous lateral equivalents of the Matanuska Formation southeast and southwest of the Talkeetna Mountains have been fairly well described by others, but no one has described the paleomicroflora of the Matanuska Formation or compared it to other Campanian-Maastrichtian paleomicrofloras from Alaska and the northern Pacific Rim. Nor have Matanuska Formation paleofloras been used to interpret paleoclimates or to reconstruct Late Cretaceous paleolatitudes of the Talkeetna Mountain Range. Such reconstructions, provided herein, will enhance understanding of the Campanian-Maastrichtian paleobiogeography of the Matanuska Formation and place temporal constraints on the docking time of the Wrangellia Terrane.

Purposes of this study

1.) To reconstruct the paleoclimate and paleogeography of southcentral Alaska during the Campanian and Maastrichtian based on paleomicrofloral data from the

Matanuska Formation. The results of this reconstruction will constrain the timing of accretion of the Wrangellia Composite Terrane to ancestral Alaska.

2.) To determine whether the Matanuska paleoflora was a transitional continental margin paleoflora specific to southcentral Alaska, as intimated by Kryshtofovich (1918) and Hollick (1930), or part of a single continental margin flora found throughout the entire North Pacific Rim region from California to the Russian Far East.

3.) To determine whether or not the *Aquilapollenites* Province flora present in northern and central Alaska intermingles with the Continental Margin Province flora in southcentral Alaska.

Methods

1.) Tabulation of the total number of pollen and spore taxa in assemblages recovered from exposures of the Matanuska Formation in the Talkeetna Mountains.

2.) Biostratigraphic dating of the Campanian, Campanian-Maastrichtian and Maastrichtian units of the Matanuska Formation by comparison with the first occurrence data of Nichols and Sweet (1993).

3.) Reconstruction of general paleolatitudes for the Campanian, Campanian-Maastrichtian, Late Maastrichtian and

Latest Maastrichtian units of the Matanuska Formation using geographically endemic pollen taxa defined by Nichols and Sweet (1993).

4.) Evaluation of paleoclimate differences across Alaska by comparing the Campanian-Maastrichtian palynological records of northern and central Alaska to paleomicroflora data from the Matanuska Formation in southcentral Alaska.

5.) Comparison of the Matanuska paleomicrofloras to coeval paleomicrofloras from the North Pacific Rim to determine whether or not a continuous maritime flora ranged from northern Japan and the Russian Far East to British Columbia, Canada, Washington and California during the Campanian and Maastrichtian.

Conclusions

After reviewing the current literature on the paleopalynology, paleoclimate and paleogeography of Alaska, and collecting and analyzing a suite of samples for this study, the following conclusions were reached:

1.) The southcentral Alaska paleomicroflora contains taxa characteristic of a subtropical Continental Margin Province and taxa typical of the *Aquilapollenites* Province of North America and the Russian Far East. Overall, the

combined Matanuska, Chignik and Kaguyak paleofloras have a greater number of pollen species of the *Aquilapollenites* Group, a greater number of species of the Proteaceae Group, and greater diversity of spore species than all the other recorded North Pacific Rim Continental Margin paleofloras.

Within Alaska, three compositionally distinct Campanian-Maastrichtian age paleomicrofloras can be recognized. These represent the northern, interior, and southcentral regions. These paleofloras exhibit a north-south increase in diversity of pollen taxa of the *Aquilapollenites* and Proteaceae Groups.

Due to the absence of Proteaceae Group pollen, the interior Cantwell paleomicroflora is most similar to the *Aquilapollenites* Province of interior western North America, indicative of a desert-like, arid and warm climate. The Colville paleomicroflora of Arctic Alaska is problematic because it contains numerous pollen species representative of the *Aquilapollenites* Province in combination with elements of the Continental Margin Province. The presence of Proteaceae pollen species and *Mancicorpus anchoriforme* (Srivastava, 1972) in the Colville paleoflora suggests that it may actually represent a previously unrecognized Arctic Continental Margin paleoflora. The low diversity of *Aquilapollenites* and Proteaceae Group species in the Arctic

flora is, compared to southcentral Alaska, considered indicative of a more arid, cool-temperate ecosystem.

2.) Biostratigraphically significant pollen taxa recognized by Nichols and Sweet (1993) from CWIS deposits are present in the Matanuska paleoflora. Their presence establishes the age of the Matanuska paleoflora as Late Maastrichtian.

3.) Geographically endemic pollen taxa place the Matanuska Formation between 60° and 70° N during the Late Maastrichtian.

4.) Predominant pollen and spore taxa suggest that the Matanuska, Chignik, and Kaguyak formations were deposited in a warm and humid subtropical climate on a continental margin.

5.) Several florules within the Matanuska Formation contain pollen and spore taxa mixed with tephra. The sequence in which specific taxa appear, relative to the occurrence of tephra, is diagnostic of volcanic recovery assemblages.

II. Review of the Literature

Introduction to the Late Cretaceous paleofloras of Alaska

The Late Cretaceous Matanuska Formation, southcentral Alaska, has been the subject of repeated studies since Alaska was acquired from Imperial Russia and became a U. S. Territory in 1867. Extensive geologic research has been conducted by the U. S. Geological Survey (USGS), the State of Alaska, and the petroleum industry in order to map and evaluate mineral and hydrocarbon wealth. Numerous results and syntheses have been published, primarily by the U. S. Geological Survey, the State of Alaska Division of Geological and Geophysical Surveys, and science journals. However, no literature on Campanian-Maastrichtian nonmarine microfloral assemblages from the Matanuska Formation has yet been published.

Collection of Late Cretaceous fossil plants from Alaska began in the 1890's, and palynological studies began in the late 1950's. A significant database of published paleobotanical and palynological information now exists. However, an overall synthesis of the Campanian-Maastrichtian paleofloras and palynology of Late Cretaceous Alaska, including interpretations of paleoclimates and

reconstructions of paleolatitudes, has yet to be achieved. This literature review was compiled, in part, to bring together and assess previous studies of Campanian-Maastrichtian floras, paleolatitudes, paleogeographic reconstructions and paleoclimates of Alaska.

The Matanuska Formation has been studied by the USGS since the early 1900's, by State of Alaska geologists since statehood in 1959, and by numerous oil exploration companies since the late 1950's. The first collection of plant fossils was taken from the Matanuska Formation in the Copper River Basin by Moffit (1918). He describes it as "Jurassic in aspect." Takhtajan (1969) considers this interpretation to be correct and describes the "floristic poverty" of the Cretaceous and Tertiary Arctic floras of North America, using the Late Albian Kungok flora of the Kuk River, Arctic Alaska (Smiley, 1966) as an example. The Kungok flora is composed predominantly of ferns, fern trees, ginkgophytes, cycadophytes, and conifers belonging to primitive form-genera, with a paucity or absence of "modern" conifers and angiosperms (Smiley, 1966). Smiley (1966) reports the rare presence 2 small leaves of a water lily which were found in the Kungok paleoflora **(Table 3)**. Takhtajan (1969) notes that Arctic paleofloras are

Table 3

Late Albian Kungok Flora, the most primitive flora found in Kuk River Area, Arctic Alaska
(modified from Smiley, 1966)

Angiosperms
Nelumbites sp. (water lily)

Gymnosperms
Conifers
Elatides sp.
Pagiophyllum sp.
Taxodiaceous form resembling *Taiwania*
Amentotaxus sp.
Cephalotaxopsis sp.
Podozamites sp.

Ginkgophytes
Ginkgo sp.
Baiera sp.

Cycadophytes
Ctenis sp.
Nilssonia sp.
Zamites sp.

Pteridophyta
Dicksonia spp. (tree ferns)

"secondary and derived", and that the Kungok flora can be described "Jurassic in aspect" for the following reasons: 1.) the gymnosperms resemble those found in Jurassic Arctic assemblages from other parts of the world, and 2.) the Jurassic composition of the Arctic paleofloras continues

until the end of the late Early Cretaceous (Albian).

The Kennicott paleoflora (Moffit, 1918; Takhtajan, 1969) **(Table 4)**, has been dated by Moffit (1918) as early Late Cretaceous based on the presence of the ammonite *Phylloceras* cf. *P. ramosum* Meek. He states that the invertebrate bed from which this species was recovered is "intimately associated in the same beds" with the fossil Kennicott megaflora. Knowlton (*in* Moffit, 1918) states, however, that this fossil plant assemblage "belongs to a Jurassic flora," and that it contains specimens indistinguishable from fossil species found in Upper Jurassic floras from England, Spitzbergen, Siberia, Germany, France, and Sweden. Takhtajan (1969) considers the Kennicott paleoflora to be one of many Arctic paleofloras and concurs with Knowlton (*in* Moffit, 1918) that the composition of the Kennicott flora is "Jurassic in aspect" because it lacks angiosperms but contains "primitive" conifers like those found in Jurassic assemblages from other Arctic megafossil localities.

The literature also contains important references to Campanian-Maastrichtian paleofloras found along the Late Cretaceous continental margins of the northern Pacific Rim **(Fig. 11)**, including coastal California to British

Table 4

A partial listing of the Kennicott paleoflora
(modified from Moffitt, 1918)

Gymnosperms

Conifers
Elatides sp.
Pagiophyllum spp.
Pinus sp.

Ginkgophytes
Ginkgo sp.

Cycadophytes
Otozamites spp.
Taeniopteris spp.

Pteridospermophytes
Sagenopteris spp.

Pteridophytes
Hausmannia sp.
Dictyophyllum sp.
Cladophlebis spp.

Columbia, the Cantwell Basin in southcentral Alaska, the Lower Yukon Basin in western Alaska, the Navarin Basin in the western Bering Sea, the island of Sakhalin and the Bureya region in the Russian Far East, and the island of Hokkaido, Japan.

The literature further documents Late Cretaceous age paleofloras from deposits of the western margins of the CWIS **(Fig. 10)**, which extended northward to the Colville Basin in Arctic Alaska and southward to the Gulf of Mexico.

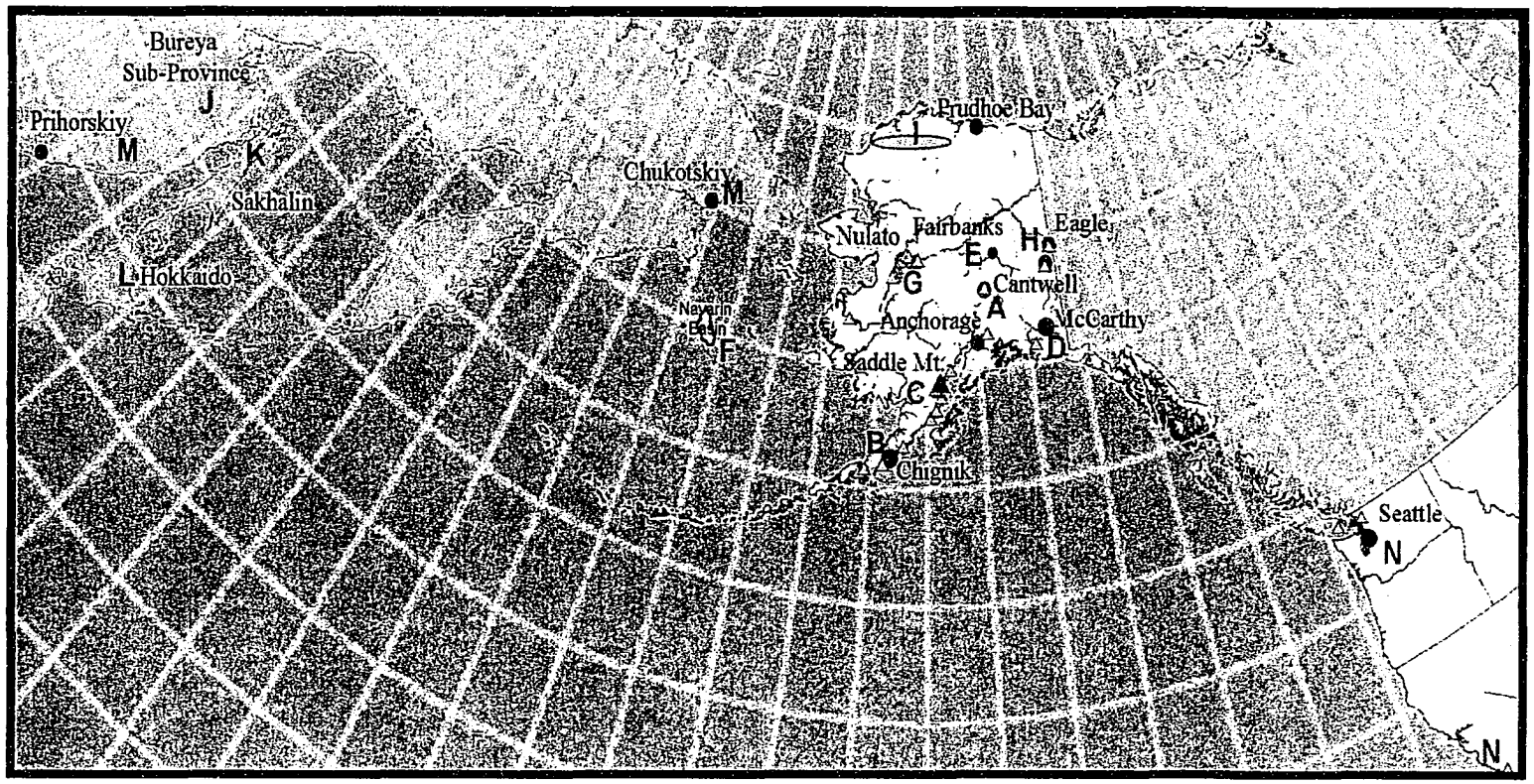

Fig. 11. North Pacific Rim paleoflora location map. Known distribution of Campanian-Maastrichtian Paleofloras in Alaska and along the North Pacific Rim: A, Talkeetna Mountains (Grantz and Jones, 1960); B, Chignik Fm. (Hollick, 1930); C, Kaguyak Fm. (Wiggins, 1976); D, Copper River Basin (Jones and Berg, 1964); E, Cantwell Basin (Ridgway *et al.*, 1997); F, Navarin Basin (Turner *et al.*, 1985); G, Kaltag-Nulato-Melozi region (Hollick, 1930); H, Chicken and Eagle, Yukon-Tanana Uplands (Foster, 1976; Foster and Igarashi, 1989); I, Ocean Point, Arctic Alaska (Frederiksen, 1987; Wahrhaftig *et al.*, 1994)); J, Bureya, Russian Far East (Samoilovich, 1966); K, Sakhalin Island (Hollick, 1930); L, Hokkaido, Japan (Miki, 1977); M, Primorskiy and Chukotsky (Markevitch, 1994); N, Nanaimo Series, British Columbia, Canada, Deming and Bellingham, Washington, and La Panza district, California (Crickmay and Pocock, 1963;

Data found in CWIS pollen assemblages from Canada southward to the Gulf of Mexico contain a succession of angiosperm pollen taxa. First appearances of selected taxa are used to define biostratigraphic zones. These assemblages also contain geographically endemic pollen taxa characteristic of the northern, central and southern CWIS (Nichols and Sweet, 1993).

A large volume of literature has also been compiled on the Late Cretaceous paleomacro- and paleomicrofloras of the Colville River Basin, which drains into the Arctic Ocean (Frederiksen, 1986, 1987, 1989, 1991; Frederiksen and Schindler, 1987; Frederiksen *et al.*, 1987; Herman and Spicer, 1997; Lewis, 1984; May and Shane, 1985; Nichols and Sweet, 1993; Parrish and Spicer, 1988; Pasch and Barker, 2000; Roehler and Stricker, 1984; Russell, 1890; Schrader, 1900; Scott and Smiley, 1979; Smiley, 1996, 1967, 1969; Spicer 1986, 1987; Spicer and Herman, 1996; Spicer and Parrish, 1986, 1990; Spicer *et al.*, 1987; Stanley, 1967; Tschudy, 1969; Vakhrameev, 1991; Wahrhaftig *et al.*, 1994; Wiggins, 1976; Witte *et al.*, 1987. For the purposes of this study, the Arctic continental margin of the Colville River Basin will be considered part of the Arctic Alaska Terrane. It is also the northwesternmost margin of CWIS.

In addition to palynological research, published studies of forest types (Wolfe, 1966, 1993), tropical and subtropical plant genera (Wolfe, 1969, 1972, 1977, 1978), Gondwanan floras (Cridland, 1963; Germeradd *et al.*, 1968; Dilcher, 1969; Martin and Harris, 1974; Johnson and Briggs, 1975; Douglas and Williams, 1982; Doyle *et al.*, 1982; Anderson and Anderson, 1983; Memon, 1983; Wiggins, 1988; White, 1990; Dettman and Jarzen, 1991), floral succession (Frederiksen *et al.*, 1987; Parrish and Spicer, 1988; Frederiksen, 1989, 1991; Herman and Spicer, 1997; Spicer and Herman, 1996), seasonal growth (Huntington, 1914; Douglass, 1916; Stokes and Smiley, 1968; Roehler and Stricker, 1984; Wolfe and Upchurch, 1987), the relationship between temperature and leaf physiognomy (Kimura and Sekido, 1975; Wolfe, 1979, 1987; Wolfe and Upchurch, 1987; Upchurch and Wolfe, 1987; Spicer and Parrish, 1986, 1990) and the impact of volcanic island arc environments on paleo-plant communities (Myers, 1993, 1996; Myers and Fisher, 1994) have facilitated interpretation of the Matanuska paleomicrofloras.

Early research on Late Cretaceous paleofloras, paleoclimate and paleogeography of Alaska and the north Pacific Rim

Tribute must be paid to the U. S. Geological Survey geologists who participated in the initial reconnaissance of Alaska. Their attention to detail in collecting specimens for paleobotanical studies and their broad and amazingly accurate interpretations laid the foundations for the work that Hollick (1930) published in his watershed document, *The Upper Cretaceous Floras of Alaska*.

As a transportation corridor to the interior of Alaska, the Yukon River became the first area of paleobotanical assessment. In the 1880's I. C. Russell conducted a reconnaissance trip to the head of the Yukon River (Russell, 1890). He was followed by numerous other Survey geologists between 1890 and 1910, including Dall (1896), Spurr (1900), Collier (1902), and Hollick (1930), all of whom made paleobotanical collections.

Spurr (1900), Stanton and Martin (1905), Paige (1906), Atwood (1911), Hollick (1930) and others conducted paleobotanical reconnaissance on the Alaska Peninsula. They collected numerous suites of plant macrofossils that were added to the collections of the U. S. National Museum at Washington, D. C. (Atwood, 1911).

Survey geologists continued exploration of Alaska throughout the first half of the twentieth century. In southcentral Alaska they conducted reconnaissance in the Matanuska Valley, the Talkeetna Mountains, the Copper River Basin, and the Wrangell Mountains. These geologists, including Moffit (1918), Martin (1926), and others, continued to enrich the Cretaceous plant fossil database of Alaska. Knowlton (*in* Moffit, 1918) analyzed Moffit's fossil plant collections from the lateral equivalents of the Matanuska Formation in the McCarthy area, Wrangell Mountains, southcentral Alaska. Knowlton reported that the fossil plants collected from these outcrops are the same species that, globally, are characteristic of other Jurassic assemblages, and that while the McCarthy fossils "belong to a Jurassic flora... [they are] intimately associated in the same beds" with a Cretaceous invertebrate fauna (*in* Moffit, 1918).

The second generation of USGS geologists to work in Alaska, including Grantz and Jones (1960), Wolfe (1966, 1969, 1972, 1977, 1978), Wolfe *et al.* (1966), Wolfe and Leopold (1967), Wolfe and Tanai (1980), and many others, continued to accumulate data on megafloral fossil

assemblages. The fossil materials were primarily of Tertiary age, but they included some Cretaceous specimens.

In the 1960's, oil and gas exploration resulted in extensive paleobotanical work in the rich deltaic and floodplain deposits of the Cretaceous North Slope. Stanley (1967) noted that the composition of the Alaska flora from the Tuluvak tongue of the Prince Creek Formation, which contains about three percent angiosperm pollen taxa, is comparable to the Cenomanian floras from Siberia which contain "low percentages of angiosperm pollen" (Bolkhovitina, 1953; Samoilovitch and Mchedlishvili, 1962). Stanley (1967) also emphasized that the Alaskan assemblages contain several angiospermous pollen taxa that are "the same as those described from Siberia," and suggests that this similarity may be characteristic of the northern Alaskan region which Zaklinskaia (1962, 1963, 1967) described as part of the *Aquilapollenites* Province.

The Chignik and Hoodoo Formations (Wiggins, 1976; Mancini *et al.*, 1978) were among the first Campanian-Maastrichtian units in peninsular Alaska to be studied using paleopalynology. Wiggins (1976, 1988) reported the presence of 10 new species of pollen of the *Wodehouseia* and *Azonia* genera, as well as the presence of *Aquilapollenites*

and Proteaceae pollen. Mancini *et al.* (1978) listed in detail the additional species of pollen found but not published in Wiggins's (1976) report.

Geologists continue to collect assemblages of plant fossils from the Arctic Alaska Terrane in the Colville River region of the Arctic Coastal Plain (Spicer and Parrish, 1986, 1990; Spicer, 1987; Parrish and Spicer 1988; Pasch and May, 1995; Spicer and Herman, 1996; Gangloff, 1998; Pasch and Barker, 2000). Paleopalynologists have identified paleomicrofloral assemblages in Arctic Alaska that record a decline in species diversity over time within an overall cooling regime (Smiley, 1966, 1967; Tschudy, 1969; Frederiksen, 1987). Several studies suggest that a subtropical Campanian climate deteriorated to a temperate climate with frost events by the Late Maastrichtian (Spicer and Parrish, 1986; Frederiksen *et al.*, 1986, 1987; Spicer, 1987; Frederiksen, 1989, 1991).

Spicer and Herman (1996) recently found two fossil specimens of Coniacian and Turonian deciduous cycad species in the Arctic. One specimen was found near the confluence of the Colville and Oolamnagavik Rivers in northern Alaska at 69° 1′ 20″ N, 154° 11′ W. The other was originally discovered near the confluence of Anadyr and Grebenka

Rivers in northeastern Russia at 64° 28′ N, 168° 56′ E. Fossils of these cycad species are also present on the Kamchatka Peninsula. The unusual deciduous characteristics of these cycads, which have "thin vine-like stems" with "persistent leaf scars," suggest to Spicer and Herman (1996) that the Late Cretaceous Arctic never hosted a subtropical climate. Until recently, however, the general assumption has been that a uniform subtropical paleoclimate prevailed throughout Alaska during the Late Cretaceous.

Very little information regarding the paleoclimate and paleogeography of the non-marine unit of the Matanuska Formation has been published. Campanian-Maastrichtian continental margin nonmarine paleoecosystems that extended from the Pacific margin of the Russian Far East to northern Japan and across the Bering shelf to the Pacific coast of North America have been described as individual paleofloras but not as one coherent continental margin floristic province.

Description of the Matanuska Formation

By 1898 Mendenhall (1900), a Survey geologist, had completed reconnaissance geology of the Matanuska Valley and Talkeetna Mountains. He recognized the marine

character of the Cretaceous age deposits in these regions. Later, Martin and Katz (1912) described the type section of the Matanuska Formation along Granite Creek, about one half mile north of its confluence with the Matanuska River (Martin, 1926; Grantz and Jones, 1960). Subsequently, Martin (1926) named it the Matanuska Formation **(Fig. 12)** and estimated the overall thickness of the type section to be over 1,240 m (4,000 ft). In most places the Matanuska Formation lies unconformably upon Jurassic limestones of the Talkeetna Formation and is unconformably overlain by the Paleocene-Eocene Chickaloon Formation (Grantz and Jones, 1960), which was derived from an unidentified, highly metamorphosed parent rock northeast of the Talkeetna Mountains (Kirschner and Lyon, 1973).

Based on invertebrate fossils, Grantz (1964) reported that the Matanuska Formation in the Granite Creek area represents a seaward facies, while the outcrops in the Nelchina area to the north of Granite Creek contain carbonaceous scraps and lenticular channel conglomerates suggestive of a nearshore environment. Grantz (1964) found a section of the Matanuska Formation greater than 4,150 meters (14,000 feet) thick in the Nelchina area. There he identified three units: a silty claystone, siltstone and

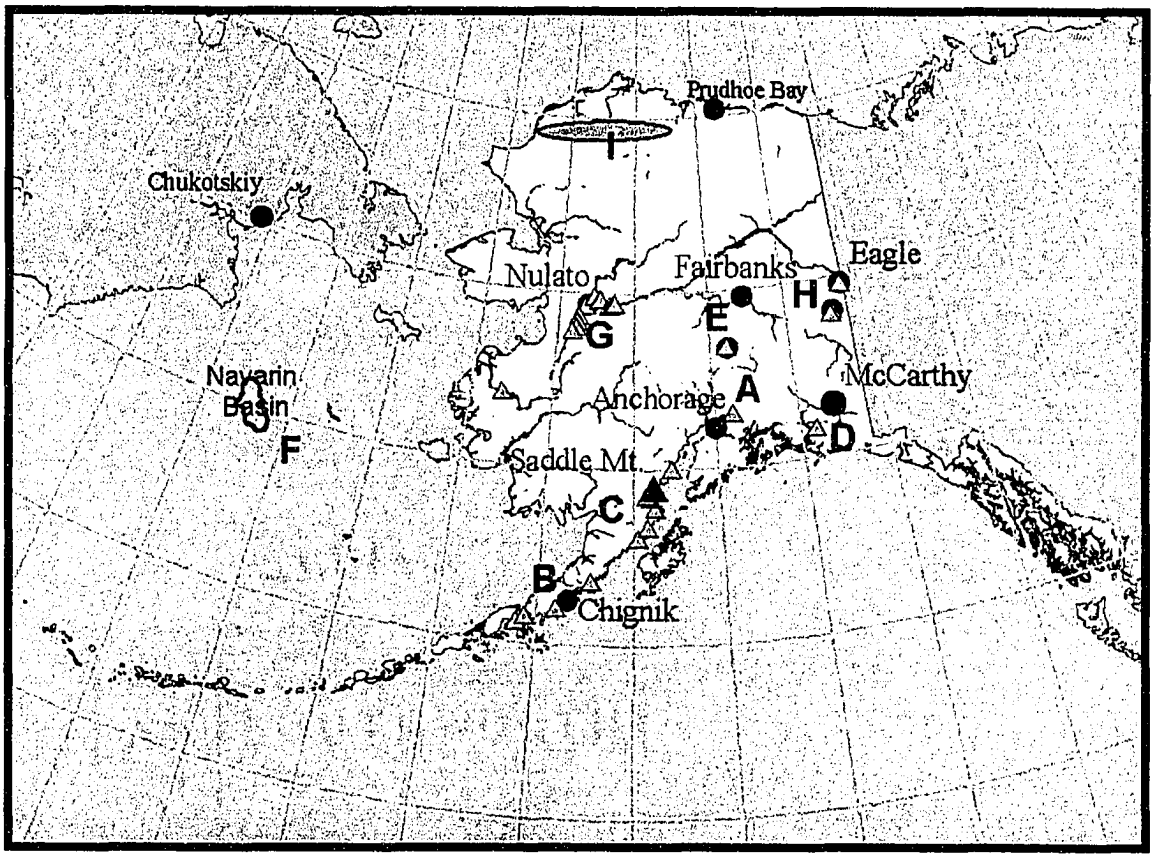

Fig. 12. General locations of the Matanuska Formation and coeval Campanian-Maastrichtian outcrops in Alaska: A, Matanuska Formation and lateral equivalents, including Cook Inlet Basin sedimentary rocks (Grantz and Jones, 1960); B, Chignik and Hoodoo Formations (Detterman *et al.*, 1996); C, Kaguyak Formation (Magoon *et al.*, 1980); D, McCarthy, Copper River Basin (Jones and Berg, 1964); E, Lower Cantwell Formation (Csejtey *et al.*, 1992; Ridgway *et al.*, 1997); F, Navarin Basin units (Turner *et al.*, 1985); G, old village sites of Kaltag, Nulato, and Melozi (Hollick, 1930); H, Chicken and Eagle Basin units, Yukon-Tanana Terrane (Foster, 1976; Foster and Igarashi, 1989); I, Prince Creek Formation, Colville Basin (Wahrhaftig *et al.*, 1994). The yellow triangles and ovals represent outcrops; the red circles represent cities, towns or villages; the black triangle represents the volcano Mt. Douglas.

basal sandstone of Albian to Cenomanian age; a claystone and siltstone of Campanian age; and a siltstone, sandstone and conglomerate of Maastrichtian age. He stated that these three thick lithologic units warrant designation as separate formations, with the Matanuska name elevated to Group status, but he did not formally name them. Finally, he noted that the three units are present throughout the Matanuska Formation (Grantz, 1961a, 1961b, 1964).

The type section at Granite Creek was originally dated on the basis of constituent invertebrate fossils **(Table 5)**, which Martin (1926) stated are found at several sites on the Alaska Peninsula and also in the general Indo-Pacific fauna and are "undoubtedly" of Upper Cretaceous age. The Indo-Pacific fauna, to which Martin compared the Matanuska Formation fossils, has been identified at the following localities: in the Chico Formation, California; Nanaimo, Vancouver Island, British Columbia; India; Japan; and Sakhalin (Martin, 1926). The late Early Cretaceous to Late Cretaceous (Albian to Maastrichtian) age of the invertebrate assemblages from the Matanuska Formation has been confirmed by numerous others, including Jones (1963). Isolated sections of the Matanuska Formation crop out regionally in the Matanuska Valley, in the Talkeetna

Table 5
Upper Cretaceous invertebrate fossils in the Matanuska Formation, recognized as part of the Albian to Maastrichtian age Indo-Pacific fauna used to date the type section
(modified from Martin, 1926)

Site	Taxon	Location
Site 6689		**Granite Creek**
	Bivalvia	
	Inoceramus gen. Sowerby 1814	
	Inoceramus cf. *I. labiatus* Schlotheim 1813	
Site 6696		**Granite Creek**
	Gastropoda	
	Amberleya gen. Morris and Lycett 1851	
	Amberleya sp.	
	Ammonoidea	
	Desmoceras sugata Kossmatt 1895	
	Phylloceras gen. Suess 1865	
	Phylloceras sp.	
	Pachydiscus gen. Zittel 1884	
	Pachydiscus sp.	
Site 6694		**Kings River**
	Bivalvia	
	Ostrea gen. Linné 1758	
	Ostrea sp.	

Mountains, and in the Copper River Basin. They are composed predominantly of marine sediments of Albian to Maastrichtian age.

Nonmarine units of the Matanuska Formation occur locally in small scattered outcrops throughout the Talkeetna Mountains (Grantz, 1960). These units are conglomerates, sandstones and shales of a subgreywacke

association (coarse grey sandstones, conglomerates, coals, basalts, and arkose), which are of interest because they contribute to the understanding of paleoecosystems. These sediments were probably derived from the unroofing of two major batholiths in southcentral Alaska: the Aleutian Range-Talkeetna Mountains magmatic arc of Middle to Late Jurassic age; and the Alaska-Talkeetna Range batholiths, emplaced during the Cretaceous and Early Tertiary. Both batholiths are located southwest of the modern Talkeetna Range (Hudson, 1979, 1983; Wallace *et al.*, 1989) **(Fig. 13)**. Reed and Lanphere (1973) presented data for Late Cretaceous and early Tertiary Alaska Range-Talkeetna Mountains batholiths which showed these plutons were generated in response to northwest directed subduction.

Southeast of the Talkeetna Mountains, the Copper River Basin **(Fig. 12)** contains two units of the Matanuska Formation (Jones and Berg, 1964). The K_2 unit is Coniacian to Campanian age based on *Inoceramus* fragments similar to *Inoceramus uwajimensis* in the lower beds and several species of ammonites and *Inoceramus* in the middle beds of the unit **(Table 6)**. The K_3 unit is Late Campanian to Maastrichtian age based on superposition above the

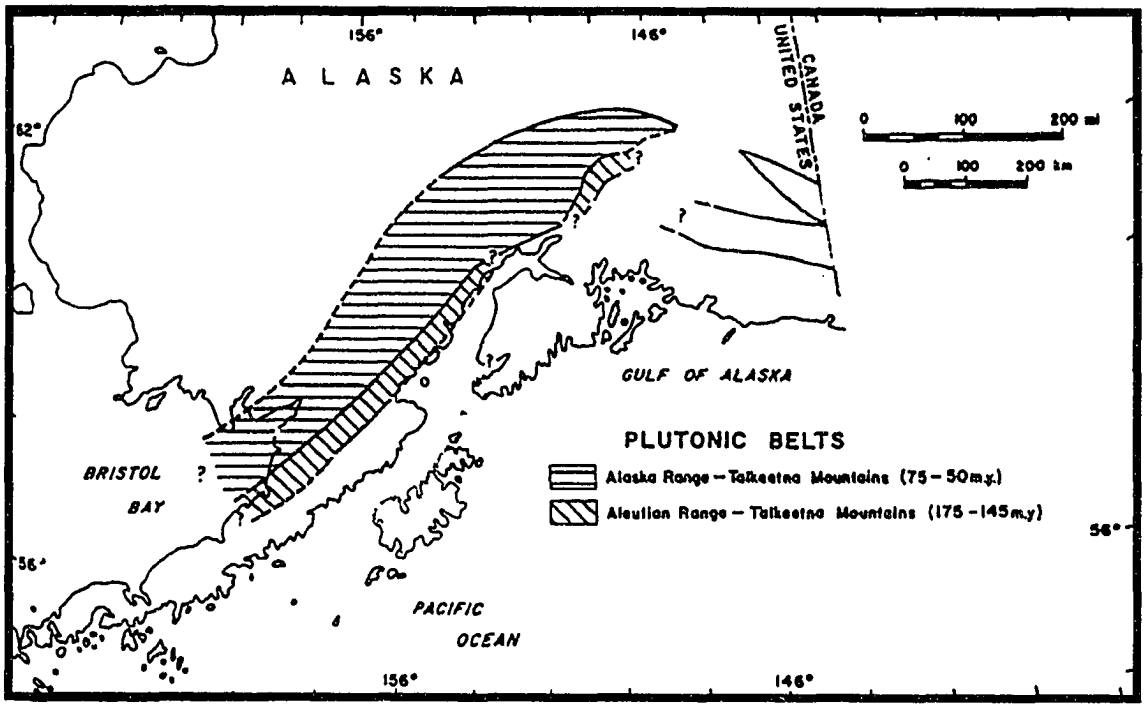

Fig. 13. Mesozoic magmatic arcs in southcentral Alaska. Locations and ages of igneous bodies in the Aleutian Range-Talkeetna Mountains and the Alaska Range-Talkeetna Mountains (modified from Hudson, 1979).

Campanian beds. U. S. Geological Survey geologists Moffit and Overbeck (*in* Moffit, 1918) described these units where they flank the Wrangell Mountains and placed them into three lithologic groups: a lower sandstone unit; a middle unit of black and red shale with interbedded limestone and plant-bearing concretions; and an upper unit composed of a massive conglomerate, sandstone, arkose and sandy shale.

The best known section of Matanuska Formation nonmarine rocks is exposed at Mazuma Creek **(Fig. 14)**, in

Table 6

Late Cretaceous invertebrate fossils used to date the K_2 unit of the Matanuska Formation in the Copper River Basin
(modified from Jones and Berg, 1964)

Age	Taxon
Late Coniacian to Early Santonian (middle beds)	
	Ammonites (cephalopod mollusks)
	Kossmaticeras gen. Spath 1922
	Kossmaticeras sp.
	Damesites gen. Matsumoto 1942
	Damesites sp.
	Bostrychoceras gen. Hyatt 1900
	Bostrychoceras sp.
	Yokoyamaoceras jimboi Matsumoto 1959
	Gaudryceras gen. Grossouvre 1894
	Gaudryceras sp.
	Baculites gen. (cephalopod mollusks) Lamarck 1799
	cf. *yokoyamai* Tokunaga and Shimizu 1926
	B. cf. *schencki* Matsumoto 1959
	Scaphites gen. (cephalopod mollusk) Parkinson 1811
	Scaphites sp.
	Otoscaphites gen. (cephalopod mollusk) Wright 1953
	Otoscaphites sp.
	Inoceramus gen. (bivalves) Sowerby 1811
	Inoceramus yokoyamai Nagao and Matsumoto 1940
	I. cf. *uwajimensis* Yehara 1924
	I. cf. *cordiformis* Sowerby 1812
Campanian (upper beds)	
	Ammonite spp. (cephalopod mollusks)
	Eupachydiscus haradai Matsumoto 1959
	Anapachydiscus gen. Yabe and Shimizu 1926
	Hauericeras aff. *H. gardeni* Bailly 1855
	Inoceramus gen. (bivalves) Sowerby 1811
	Inoceramus sp.
	Inoceramus schmidti Michael 1873

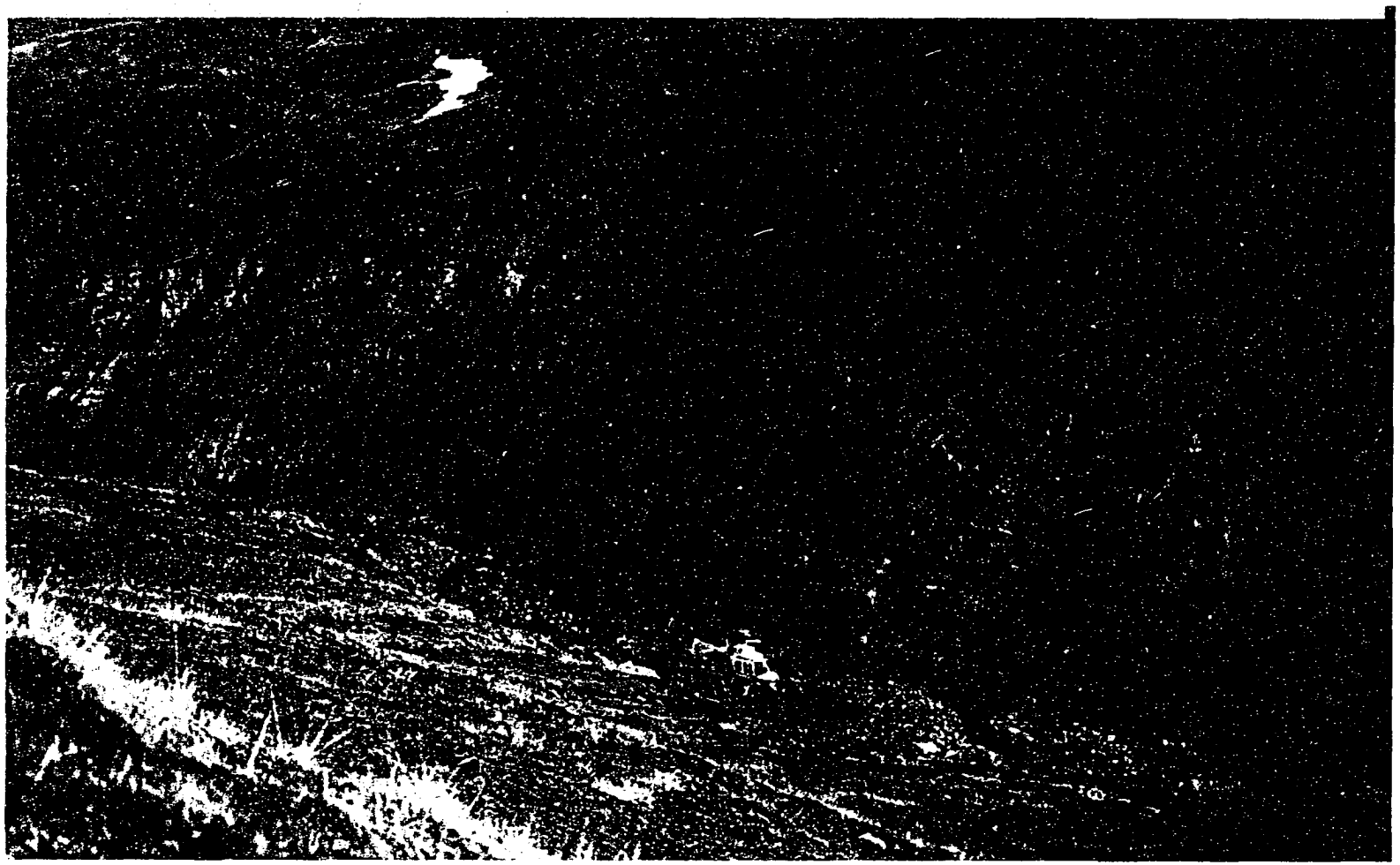

Fig. 14. Mazuma Creek outcrop. Note the normal fault on right and the marine transgression which proceeded from right to left. The marine unit is gray and lies conformably above the non-marine orange sandstones, coal seams and conglomerates. Note helicopter for scale (Photo by Anne Pasch).

the Talkeetna Mountains north of Anchorage. The outcrop reveals a conformable contact between non-marine and marine sediments and is a superb example of a regional marine transgression. The marine sediment overlies a nonmarine coal-bearing unit and defines a small segment of the island arc shoreline (Fisher and Magoon, 1978). The Mazuma Creek outcrop is the primary site for this project; fifty sediment samples were collected from it and processed for pollen and spores **(Appendix A)**.

Tectonic history. Prior to the introduction of plate tectonic theory, the area that includes the Matanuska Valley and the Talkeetna Mountains was described as the Matanuska Geosyncline (Payne, 1955) and as a narrow seaway (Grantz and Jones, 1960). Jones and Clark (1973) described the Matanuska Formation as deposits of a transgressing sea.

The tectonic terrane history of the Matanuska Formation is far more complex and is inextricably linked with other Jurassic-Cretaceous-Tertiary flysch deposits (Csejtey *et al.*, 1992) between the central Alaska Range and the southcentral continental margin of Alaska. Csejtey *et al.* (1992) reported that the flysch consists of

> turbidite deposits of a once large but narrowing and subsequently collapsed oceanic basin between converging continents.

Moore (1973b) suggested that this

> arc-trench system [which] may have bordered ... the [entire] Pacific margin of Alaska at various times during the Mesozoic

was continuous from southwestern Alaska along the Bering Shelf edge to northeastern Siberia (Moore 1974) based on eugeosynclinal "Triassic-Cretaceous deep-sea deposits of the Koryak Mountains in eastern Siberia" (Moore, 1973a). Hudson (1979) identified the Upper Cretaceous and Paleocene sedimentary rocks of the Cook Inlet region as volcanogenic detritus and tuff, and Magoon *et al.* (1980) interpreted them as forearc deposits. Nilsen and Zuffa (1982) noted that these "forearc basin or arc-trench gap deposits" were generally transported southward. Moore and Connolly (1977) and Winkler (1992) described the Matanuska Formation as a forearc apron deposit derived from the Alaska-Aleutian Range batholith. In addition, Fisher and Magoon (1978) described the Matanuska Formation as a marine forearc basin deposit with its northern margin at the southern flank of the Alaska Range **(Fig. 7)**. The southern flanks of the

Alaska Range outline the ancient continental margin and the subduction zone into which the oceanic Kula Plate plunged during the Mesozoic (Richter and Jones, 1973).

The region that includes the forearc basin deposits, bounded to the north by the Alaska Range and to the south by the Mesozoic oceanic trench marginal to the continent (Moore, 1973a, 1973b), will be referred to as the Late Cretaceous Matanuska Seaway in this paper. This seaway was reduced to the much smaller proto-Cook Inlet by northerly directed subduction along the Alaska continental margin between 75 to 50 million years ago (Hudson, 1979).

The bedrock of the Talkeetna Mountains represents an extinct Jurassic volcanic island arc, which is overlain by very fossiliferous Jurassic limestone shelf deposits of the Talkeetna Formation (Grantz and Jones, 1960). The bedrock of the Matanuska Valley region is also interpreted as an intra-island volcanic arc of Jurassic age (Burns *et al.*, 1991). Nokleberg *et al.* (1994b), however, stated that the portion of the Matanuska Formation found in Matanuska Valley "is the youngest part of the Chignik subterrane," which is one of two components which make up the Peninsular Terrane.

Paleomagnetic data suggest that the Talkeetna Volcanic Island Arc formed somewhere between the equator and 30° N (Hillhouse and Grommé, 1984). Plafker *et al.* (1989) suggest that the Talkeetna Arc was part of a magmatic belt which may have been continuous along the continental margin from Canada to Mexico. Based on paleomagnetic data, Wilson and Weber (1994) believe that the Talkeetna Arc was parallel to the Oregon coast during the Jurassic.

By the Late Cretaceous, plate movements had slowly rafted the Talkeetna Volcanic Island Arc northward as a component of the Peninsular Terrane, which is a part of the greater Wrangellia Composite Terrane (WCT) (Nokleberg *et al.*, 1994a, 1994b). Paleomagnetic data indicate that the Wrangellia block was rafted approximately 27° poleward (3,000 km or 1,875 miles) (Hillhouse and Coe, 1994) prior to collision with the North American craton. As the Wrangellia block approached the southern continental margin of Alaska, it shed sediment into the Matanuska Seaway.

Accretion of the Wrangellia Composite Terrane to the southern continental margin of Alaska occurred about 65-55 M. y. (Hillhouse, 1987). Hillhouse (1987) also states that central and western Alaska, including the northern Talkeetna Mountains, rotated as a single block

> as much as 50° counterclockwise...about a hinge line near 146° W ...between 68 M.y. and 44 M.y. ago.

He suggests that compression between North America and Asia during opening of the North Atlantic may have produced the block rotation.

Authors place the Peninsular Terrane at several different paleolatitudes during the Late Cretaceous and Early Tertiary. They also disagree as to the age of docking. In the Cantwell region, Hillhouse *et al.* (1985) proposed a Late Cretaceous to Eocene paleolatitude of 81° N $\pm$ 8° for the terrane, while Panuska and Macicak (1986) suggested 71° N $\pm$ 10°. Panuska and Stone (1985) stated that the volcanic rocks from the Talkeetna Mountain region yield an Eocene paleolatitude of 80° N $\pm$ 9°, whereas Hillhouse *et al.* (1985) suggested 76° N $\pm$ 10° for the same epoch. Panuska and Macicak (1986) placed the early Eocene southern Talkeetna Mountains at the relatively high latitude of 80° $\pm$9° N. The modern latitude of the Talkeetna Island Arc is 61° N.

Grantz (1966) suggested the counterclockwise rotation of the southcentral region of Alaska was a response to convergence of Siberia and North America during late Cretaceous and early Tertiary time. Paleomagnetic data

(Globerman and Coe, 1984; Thrupp and Coe, 1986) suggest that counterclockwise rotation by the Wrangellia Terrane of as much as 45° to 55° has occurred since the Late Cretaceous. More recent paleomagnetic data presented by Hillhouse *et al.* (1985), however, suggests that the Talkeetna region reached its modern latitude after a 30° counterclockwise rotation relative to the craton. Thus, the initial docking of the Talkeetna Island Arc within the Wrangellia Terrane must have occurred during the Late Cretaceous at a higher latitude (Hillhouse *et al.*, 1985; Panuska and Macicak, 1986).

Reduction of the Matanuska Seaway. During the Late Cretaceous-Early Tertiary, a sedimentary wedge was accreted southeast of the Talkeetna Mountains. This sedimentary wedge is recognized as the Chugach Terrane (Hudson, 1979, 1983; Wallace and Engebretson, 1984) **(Fig. 7)**, which created a barrier to sediments moving from the Talkeetna Mountains southeast toward the Copper River Basin. Drainage was not blocked to the southwest, however, so sediments from interior Alaska flowed through the Cantwell flysch basin, near the center of the Alaska Range, into the Matanuska embayment (Moore, 1973a). At the same time the embayment was receiving sediments from batholiths of the

Talkeetna Mountains (Moore, 1973). Since the beginning of the Tertiary this drainage system has continued to fill the Matanuska Seaway, reducing it to the modern Cook Inlet Basin (Wahrhaftig *et al.*, 1994) **(Fig. 3)**.

Tectonic activity also contributed to reduction of the Late Cretaceous Matanuska Seaway. Fisher and Magoon (1978) believed that Cook Inlet was uplifted by anticlinal folding of sediment beneath the inlet during the early Paleocene subduction events. Burk (1965) noted that deformation and folding of sediment on the Alaska Peninsula and in the Cook Inlet area continued during the Pliocene. Wallace and Engebretson (1984) concluded that reduction of the Late Cretaceous Matanuska Seaway to a Maastrichtian-Tertiary embayment, and then to the Tertiary proto-Cook Inlet, was a response to subduction of the Kula Plate. Collision with terranes to the north may also have contributed to reduction of the seaway as early as Maastrichtian (Fujita and Newberry, 1983) or as late as Eocene (Grantz, 1966).

Outcrop locations of the Matanuska Formation. The Matanuska Formation was deposited in a forearc basin adjacent to the Mesozoic continental margin during a marine transgression (Nokleberg *et al.*, 1994b). The Formation is not exposed as a continuous sequence at any one location,

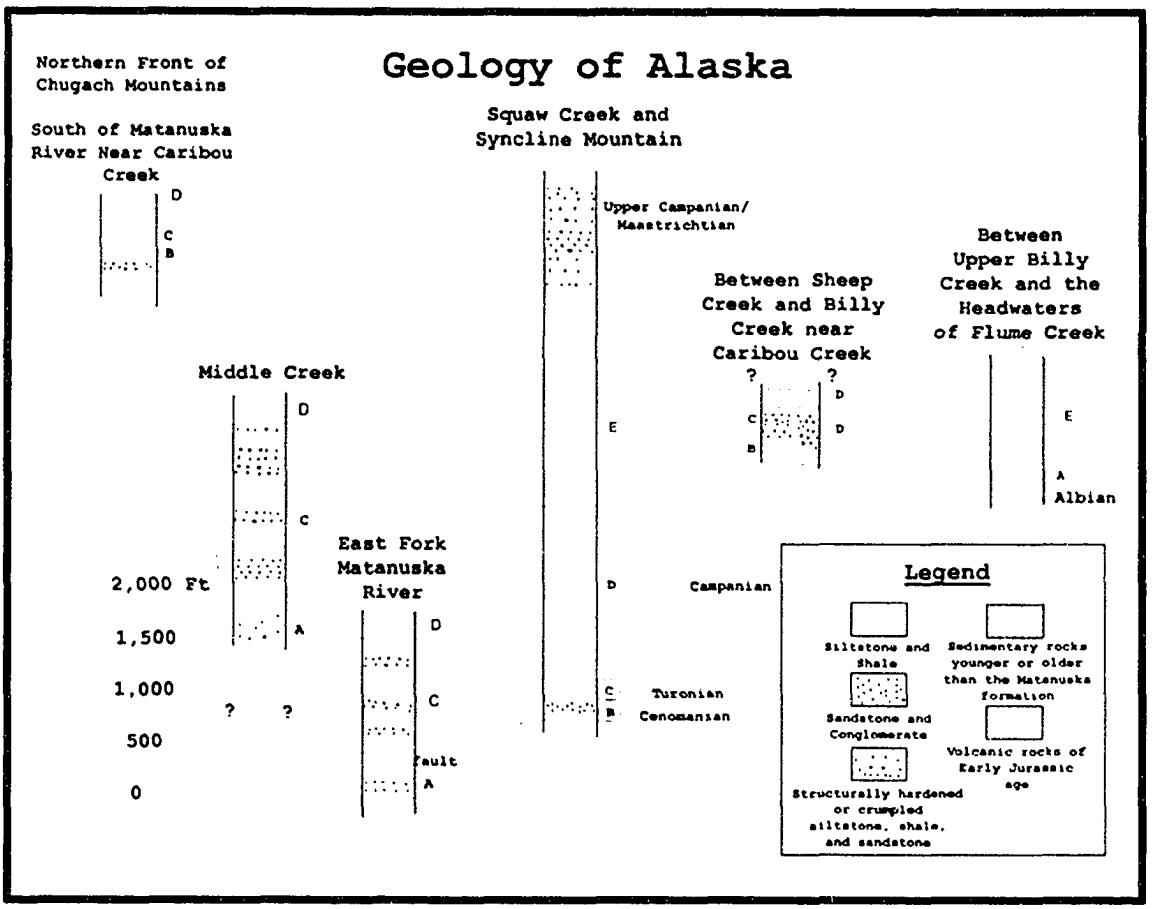

Fig. 15. Stratigraphic sections, Matanuska Formation. Combined columnar sections of the Matanuska Formation, Nelchina area, Alaska. Fossil assemblages in lithologic units D and E are Campanian-Maastrichtian, unit C is Turonian, unit B Cenomanian, and unit A is Albian (modified from Grantz and Jones, 1960).

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except possibly in the Nelchina District where Grantz (1964) reported what he believes to be a complete section (**Fig. 15**). He based this interpretation on the presence of critical invertebrate fossil assemblages, including the

index species *Diplomoceras notabile* (ammonite) and *Inoceramus schmidtii* (bivalve) **(Table 7)**.

The Matanuska Formation contains units from every Stage in the Late Cretaceous Series, as well as two units of late Early Cretaceous age. Units crop out throughout the Talkeetna Mountains and have been sampled by drill cores beneath Cook Inlet Basin (Jones, 1963). A single Albian non-marine unit is located at Ammonite Creek in the Talkeetna Mountains. Marine outcrops of Albian, Cenomanian and Turonian age have been identified within the Matanuska Valley, north of Sheep Mountain. Coniacian to Santonian non-marine deposits have not been recognized, but marine deposits of those ages have been identified in the Cook Inlet Basin (Payne, 1955; Kirschner and Lyon, 1973). Marine units of Campanian, Campanian-Maastrichtian and Maastrichtian age have been identified at Mazuma Creek, Granite Creek, Syncline Mountain, Slide Mountain, Hicks Creek **(Map in pocket)**, in numerous road cuts throughout the Upper Matanuska Valley **(Map in pocket)**, and in marine sediments underlying the Cook Inlet Basin (Payne, 1955; Jones, 1963; Kirschner and Lyon, 1973) **(Figs. 7 and 8)**. The only well exposed non-marine unit of Maastrichtian age is located at Mazuma Creek **(Fig. 14)**.

Table 7

Fossil assemblages used to date the Matanuska Formation
(modified from Grantz and Jones, 1960)

Lithologic Unit	Age	Invertebrate Fossils
E	Upper Campanian and Maastrichtian	*Pachydiscus (Neodesmoceras)* n. sp. Grantz and Jones 1960 *Pachydiscus ootacodensis* Stoliczka 1898 *Pachydiscus* n. sp. Grantz and Jones 1960 *Pseudophyllites indra* Forbes 1846 *Baculites occidentalis* Meek 1857 *Baculites* n. sp. Grantz and Jones 1960 *Didymoceras hornbyenses* (Whiteaves) Matsumoto 1959 *Diplomoceras notabile* Whiteaves 1903 *Inoceramus subundatus* Meek 1861
D	Campanian	*Inoceramus schmidtii* Michael 1873 *Anapachydiscus* sp. Yabe and Shimizu 1926 *Helcion* cf. *H. giganteus* Schmidt 1973
C	Turonian	*Sciponoceras* aff. *S. bohemicus* Fritsch in Fritsch and Schloenbach 1872 *Inoceramus* aff. *I curvierii* Heinz 1932
B	Cenomanian	*Calycoceras* gen. Hyatt 1900 *Calycoceras* sp. Grantz and Jones 1960 *Inoceramus* n. sp. *I yabei* Nagao and Matsumoto 1939
A	Albian	*Buchia* gen. Cox 1969 *Brewericeras hulenense* Anderson 1938 *Freboldiceras singulare* Imlay 1959

Coal and volcanic ash deposits. Coal deposits that range from several centimeters to a meter thick are found locally in the Matanuska Formation. In the Talkeetna

Mountains, the coals are intercalated with conglomerate-rich fluvial and deltaic deposits. Tonsteins, seams of altered volcanic ash in coals, are also in the non-marine sediments. These ash layers record on-going continental margin volcanism related to the accretion of the Wrangellia Composite Terrane (WCT) to the North American continent (Wallace and Engebretson, 1984; Hillhouse, 1987; Grantz, personal comm., 1995). The coal deposits confirm the presence of swampy environments along the island arc shoreline (Merritt, 1987).

Lateral equivalents of the Matanuska Formation

Remnants of the Late Cretaceous continental lowlands that fringed the Matanuska Seaway stretch a distance of over 1,200 kilometers (750 miles), from Pavlof Bay on the Alaska Peninsula, to Cantwell in the Alaska Range, and to McCarthy in the Copper River Basin (Moore, 1973) **(Fig. 9)**. As previously noted, the nonmarine facies of the Matanuska Formation in the Talkeetna Mountains were deposited along the coastal margin of the Talkeetna Island Arc system. These facies are laterally equivalent to much thicker, Late Cretaceous nonmarine units of the Chignik, Hoodoo and

Kaguyak Formations on the Alaska Peninsula (Nokleberg *et al.*, 1994a).

Coal deposits within these units range from several centimeters to many meters thick. Coals in the non-marine Coal Valley Member and Chignik Member of the Chignik Formation are as thick as three meters (10 ft) (Atwood, 1911). These coals are exposed on the Alaska Peninsula as far south as Herendeen Bay. Outcrops of coal are also present at Saddle Mountain on the western margin of Cook Inlet Basin (Keller and Reiser, 1959).

Coal deposits in the Chignik and Kaguyak Formations are generally thought to represent lowland swamp environments (Merritt, 1987), whereas the Hoodoo Formation is considered to be a deep-water lateral equivalent of the Chignik Formation (Detterman *et al.*, 1996).

Chignik Formation. The Chignik Formation is greater than 500 to 600 m (1,600 to 2,000 ft) thick in the area between Port Moller and Chignik Bay. The type section, one half mile inland from the northwest shore of Chignik Lagoon and difficult to access, was described by Atwood (1911). The reference section, slightly thicker and well exposed in Herendeen Bay, is over 150 m (490 ft) thick, and consists of two units: the nonmarine Coal Valley Member at Herendeen

Bay and a marine unit which also crops out at Chignik Lagoon on the Alaska Peninsula **(Fig. 8)**. The Chignik Formation unconformably overlies the Jurassic Naknek Formation. It is unconformably overlain by the Tolstoi Formation of late Paleocene to early middle Eocene age (Detterman *et al.*, 1996).

Atwood (1911) noted that the lithostratigraphy of the Chignik Formation at Chignik Bay, near Nigger and Chignik Heads, reveals the existence of a floodplain where coals were formed and a marine shoreline with preserved ripples. Hollick (1930) verified that the shallow marine environment contains fossils of nonmarine and marine plants (Hollick, 1930). Detailed studies by Fairchild (1977) and Detterman (1978) at the reference section along Chignik Lagoon show that the Chignik Formation sediments consist of cyclic nearshore marine, tidal flat, nonmarine floodplain and fluvial deposits. Coal and carbonaceous shale occur within the nearshore sandstone and siltstone units, and in two intervals of nonmarine floodplain and fluvial deposits. Marine invertebrate fossils, including the bivalves *Inoceramus balticus* var. *kunimiensis*, *I. schmidti*, and the ammonite *Canadoceras newberryanum*, indicate a late

Campanian to early Maestrichtian (Late Cretaceous) age for the Chignik Formation.

Hoodoo Formation. The reference section of Hoodoo Formation at Foot Bay is over 630 m (2,067 ft) thick, and it is composed of siltstone, sandstones and shales. The lower contact of the Hoodoo Formation is not exposed, but it is conformably overlain by the Paleocene Tolstoi Formation. The lateral contact between the Chignik and Hoodoo Formations is gradational. Detterman *et al.* (1996) concluded that the Hoodoo and Chignik Formations were formed "during a major Late Cretaceous marine transgression and that they represent two distinct facies of the same time-stratigraphic interval."

Marine invertebrate fossils in the Hoodoo Formation indicate a late Campanian to early Maestrichtian (Late Cretaceous) age. The faunal assemblage, including the ammonite *Diplomoceras* and species of the bivalve *Inoceramus*, differs from that of the Chignik Formation. Detterman *et al.* (1996) suggested that the differences indicate that either the Hoodoo Formation is slightly younger than the Chignik Formation, or that the two faunal assemblages are the result of different depositional environments.

Kaguyak Formation. The Kaguyak Formation overlies Jurassic to Early Cretaceous age units, and is overlain by nonmarine Oligocene strata and Tertiary and Quaternary volcanics (Detterman *et al.*, 1996). Fossils of the Kaguyak Formation, including *Diplomoceras notabile*, *Pachydiscus kamishakensis* Jones 1963 and *Inoceramus balticus* var. *kunimiensis*, are assigned to the *Pachydiscus kamishakensis* zone of latest Campanian to early Maastrichtian age (Jones, 1963).

The Kaguyak Formation contains both marine and nonmarine units. The marine unit, a series of turbidite deposits representing a submarine fan prograding into a deep-water environment, is over 340 m (1,116 ft) thick (Detterman *et al.*, 1996). The marine unit crops out in the Kamishak Hills, adjacent to Douglas Volcano near Cape Douglas in Lower Cook Inlet Basin (Fisher and Magoon, 1978).

The only known nonmarine unit of the Kaguyak Formation crops out farther north at Saddle Mountain on the central western margin of the Cook Inlet Basin (Magoon *et al.*, 1980) **(Figs. 2 and 8)**. The type section, visible on the sea cliffs at the mouth of the Swikshak River on the Alaska Peninsula, extends from Katmai Bay northward to Kamishak

Bay (Detterman *et al.*, 1996). Neither the upper or lower contacts are exposed at the type section, but they are visible in other local outcrops. The lower contact is estimated to be about 91 m (299 ft) below the base of the type section outcrop. Both the lower and upper contacts are unconformable.

The Saddle Mountain Member (Hastings *et al.*, 1983) outcrop is 83 m (273 ft) thick and contains coal seams as thick as three meters (10 ft) (Magoon *et al.*, 1980). The coals are interbedded with sandstones showing cross bedding, conglomerates, sandstones and siltstones, which suggest a stream and swamp environment (Magoon *et al.*, 1980).

Geology of the Alaska Peninsula

The geology of the Alaska Peninsula is very complex, and research continues to the present day. Three theories address the origin and modern position of the Peninsular Terrane and its accretion to the Mesozoic continental margin: 1.) oroclinal folding of Alaska occurred along a central N-S fold line to produce the present configuration of western and southcentral Alaska (Carey, 1955; Grantz, 1966); 2.) a forearc and subduction trench extended from

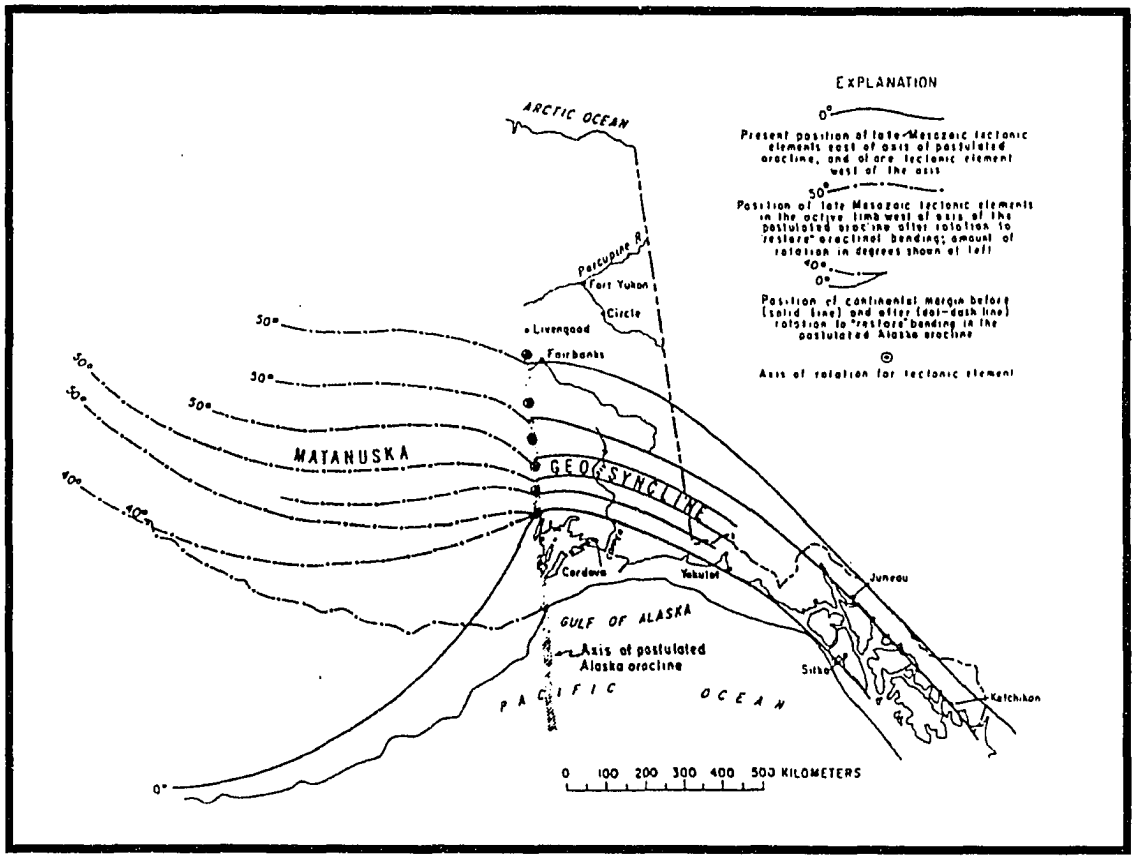

Fig. 16. Oroclinal fold. The oroclinal fold theory proposes that the Alaska Peninsula was pulled away from the Koryak Mountains of Russian Far East, located to the west of Alaska, and folded along a N-S hinge line through central and southcentral Alaska during the Late Mesozoic (from Grantz, 1966).

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the Russian Far East across southern Alaska (Moore, 1973a; Coe *et al.*, 1985; Turner *et al.*, 1985; Thrupp and Coe, 1986, 1987; Detterman *et al.*, 1996) and 3.) after the Peninsular Terrane was rafted northward and accreted to the continent, the southcentral region of the Terrane was

rotated between 30° and 50° counterclockwise (Jones *et al.*, 1978, Stone *et al.*, 1982; Hillhouse and Coe, 1994; Wilson and Weber, 1994).

The earliest interpretation (Carey, 1955) proposed that during the Eocene, the entire western land mass of Alaska rotated counterclockwise in an oroclinal fold. Grantz (1966) suggested this bending occurred along a N-S fold line, or axis of rotation, bisecting central Alaska **(Fig. 16)**. Grantz (1966) also recognized the trend of a single continuous east-west Mesozoic coastline connecting the Asian and North American continents and postulates that broad-scale bending, rather than tight compression, disassociated the Koryak, Russian Far East, portion of the coastline from the Matanuska Embayment parallel to the southcentral coastline of Alaska.

More recent studies do not support the oroclinal fold scenario. The paleomagnetic data of Coe *et al.* (1985) and Thrupp and Coe (1986, 1987), however, do place the pre-Eocene coastal margins of peninsular southcentral Alaska in strong E-W lineament. Turner *et al.*, (1985) also suggested that, based on paleomagnetic data, the entire northern Pacific coastline may have been approximately parallel to the equator. Moore (1973a) stated that a continental

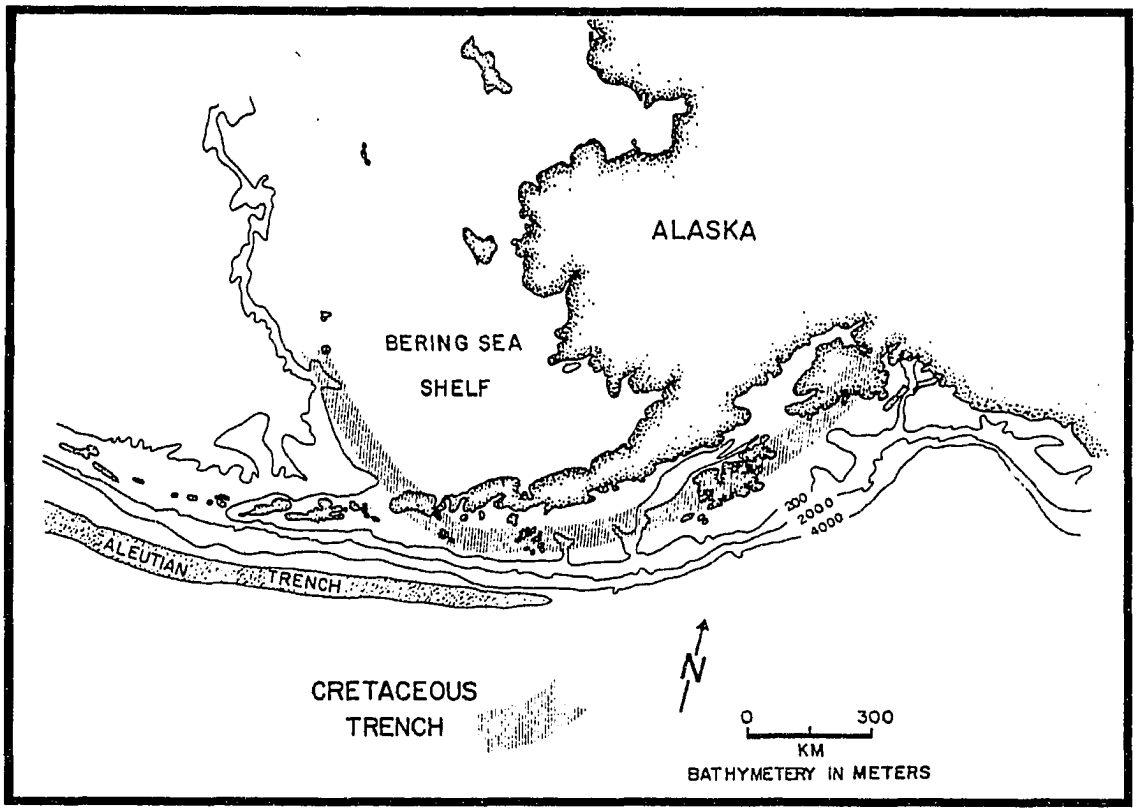

Fig. 17. Postulated Cretaceous trench. A "eugeosynclinal" trench may have extended from southcentral Alaska along the margin of the Bering Shelf to the Koryak Mountains of northeastern Siberia (Moore, 1973a).

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margin "eugeosynclinal" sequence **(Fig. 17)** developed along the continental margin and continues from southwestern Alaska along the Bering Shelf edge to the Koryak Mountains of northeastern Siberia. According to Detterman *et al.*, (1996) the Aleutian Range and the Alaska Range batholiths on the Alaska Peninsula are a result of magmatic

emplacement along this active continental margin **(Fig. 13)**. The implications are significant and suggest that a continuous forearc basin and subduction trench extended from the Russian Far East and northern Japan across southern Alaska to Canada and perhaps as far south as California.

The third and perhaps most parsimonious concept is that the Peninsular Terrane was accreted as part of the Wrangellia Composite Terrane (Hillhouse and Coe, 1994; Wilson and Weber, 1994) during the Jurassic (Jones *et al.*, 1978; Stone *et al.*, 1982). Hillhouse (1987) believed the central and western blocks of Alaska, including the northern Talkeetna Mountains, were rotated counterclockwise by east-west compression of North America and Asia during the Late Maastrichtian to Eocene. Wilson (Pers. comm., 2000) suggested that although these units were moved parallel to the North American continent and were accreted to the Alaskan land mass late in the Mesozoic, the accretion did not include oroclinal folding as first suggested by Grantz (1966). Citing the lack of evidence for folding and metamorphism in the region of the assumed pivot point, Wilson (Pers. comm., 2000) proposed that the

accretion of the Peninsular Terrane and Talkeetna Island Arc was not accompanied by oroclinal folding.

Paleofloras of the Matanuska Formation equivalents on the Alaska Peninsula

Chignik Paleoflora. Paleomacroflora, fossil plant material, has been collected for over 100 years on the Alaska Peninsula (Stanton and Martin, 1905; Atwood, 1911; Hollick, 1930) **(Tables 8 and 9)**. More recently, paleomicroflora, fossil pollen, have been found in the Chignik Formation (Mancini *et al.*, 1978; Magoon *et al.*, 1980; Wiggins, 1988) **(Table 10)**. These assemblages are important because they provide a window into the Late Cretaceous continental margin.

Knowlton (Dall, 1896) was the first to study a paleofloral assemblage from the Chignik area, collected from the Coal Valley Member of the Chignik Formation in Herendeen Bay (**Fig. 5**). He assigned a Tertiary age to this collection. Dall (1896) described the first floral assemblage from these coal bed outcrops. Subsequently, Paige (1906) collected a second assemblage of plant fossils from this area and determined this collection to be Upper Cretaceous in age. From 1894 through 1911 fossil plant

Table 8

A partial listing of the Chignik paleoflora
(modified from Stanton and Martin, 1905)

Angiosperms

Myrica sp.
Quercus spp.
Ziziphus (Zizyphys) sp.
Cercidiphyllum sp.

Gymnosperms

Conifers

Sequoia spp.
Taxodium sp.
Torreya spp.

Cycads

Anomozamites sp.
Zamites sp.

Ferns

Adiantum sp.
Osmunda sp.
Pterophyllum sp.

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collections were made at Chignik, Pavlov and Herendeen Bays on the Alaska Peninsula by U. S. Geological Survey geologists Knowlton (Dall, 1896; Spurr, 1900), Stanton and Martin (1905), Stone (1905), Paige (1906), Atwood (1911), and Hollick (1930). At these three sites, Campanian-Maastrichtian plant fossils are abundant.

At Chignik Bay, Stanton (Stanton and Martin, 1905) noted an abundance of Upper Cretaceous fossil plants. He returned with three additional collections of plant

Table 9

A partial listing of the Chignik paleoflora
(modified from Hollick, 1930)

Angiosperms
- *Aralia* sp.
- *Ficus* spp.
- *Laurus* sp.
- *Magnolia* sp.
- *Quercus* spp.
- *Vitis* sp.
- *Zizyphus* sp.

Gymnosperms

Conifers
- *Sequoia* spp.

Ginkgo
- *Ginkgo minor*

Cycads
- *Nilssonia serotina*

Ferns
- Numerous species

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material **(Table 8)** from the same unit studied by Knowlton (Stanton and Martin, 1905). Hollick (1930), a U. S. Geological Survey paleobotanist, traversed Alaska during the first decades of the twentieth century, collecting Cretaceous plant fossils, including fossils from the Chignik Formation **(Table 9)**. He reported that the Campanian-Maastrichtian paleomacroflora of the Chignik Formation is extensive, containing wood fragments, well

Table 10

Campanian-Maastrichtian palynomorphs of the Chignik, Kaguyak, Hoodoo, and Matanuska Formations
(after Wiggins, 1976, 1988; Mancini *et al.*, 1978; Magoon *et al.*, 1980)

Chignik Formation

(Wiggins, 1976;)

Azonia sufflata Wiggins, sp. nov.
A. fabacea Samoilovitch 1961
A. fabacea subsp. *rugulos* Wiggins, subsp. nov.
A. fabacea subsp. *reticulata* Wiggins, subsp. nov., stat. nov.
A. recta (Bolkhovitina) Samoilovitch 1961
A. parva Wiggins, sp. nov.
Mancicorpus anchoriforme Wiggins 1976
Wodehouseia spinata Stanley 1961
W. capillata Wiggins, sp. nov.
W. avita Wiggins, sp. nov.

(Mancini *et al.*, 1978)

Aquilapollenites attenuatus Funkhouser 1961
A. catenireticulatus Srivastava 1968
A. parallelus B. Tschudy 1969
A. quadrilobus Rouse 1957
A. reticulatus (Mtchedlishvili) Tschudy and Leopold 1971
A. *senonicus* (Mtchedlishvili) Tschudy and Leopold 1971
A. *turbidus* B. Tschudy and Leopold 1971
Fibulopollis mirificus (Chlonova) Chhlonova 1961
Wodehouseia gracile (Samoilovitch) Pokrevskaya 1966
Proteacidites thalmanii Anderson 1960

Kaguyak Formation

(Greisbach *in* Magoon *et al.*, 1980)

Aquilapollenites bertillonites Funkhouser 1961
A. reticulatus (Mtchedlishvili) Tschudy and Leopold 1971
A. delicatus Stanley 1961
Cranwellia striata (Couper) Srivastava 1967
Wodehouseia spinata Stanley 1961
Proteacidites spp.

Kaguyak, Hoodoo, and Matanuska Formations

(Wiggins, 1988)

Proteaceous pollen
Pseudoproteaceous pollen

preserved angiosperm and conifer leaf fossils, and conifer cones. He also stated that the Chignik Paleoflora is one of two distinct Late Cretaceous assemblages in Alaska. The other assemblage, an early Late Cretaceous collection from the Lower Yukon River region, contains single species of *Ficus*, *Cinnamomum*, and *Vitus*, and multiple species of *Quercus*, *Platanus*, and *Magnolia* (Hollick, 1930) indicative of a subtropical climate. Constituent angiosperm fossils such as *Magnolia* and *Laurus* species are subtropical components; today the Order Laurales includes bay laural and avacado trees. Hollick (1930) reported that he also found fossils of gymnosperms, including Cycadales, Ginkgoales, and two species of *Sequoia* in the Lower Yukon River region. None of these gymnosperm or angiosperm species are present in Alaska today, with the sole exception of *Aralia*, or devil's club (Hulteń, 1968).

Fifty years later, Wiggins (1976) and Mancini *et al.* (1978) described the nonmarine microflora of the Chignik Formation, documenting the presence of two extinct angiosperm pollen genera, *Aquilapollenites* and *Wodehouseia*. The plants from which these palynomorphs were derived are not represented in the Alaska macrofloral record. Furthermore, fossilized plant organs belonging to

these species have never been found anywhere in the world, except for a few recently discovered staminate flowers of *Kurtziflora antherosa* in Canada which contain *Aquilapollenites* pollen (McIver *et al.*, 1991).

Kaguyak Paleoflora. The Kaguyak Formation also contains paleomicroflora important to the paleoclimate interpretation of the Alaskan continental margin (Magoon *et al.*, 1980). Wiggins (1976, 1988) identified nine pollen species of the Oculata Group and also mentions "rarely occurring" Proteaceae and pseudoproteaceous pollen (Wiggins, 1988) in the Kaguyak Formation **(Table 10)**. Wiggins also reported the presence of Proteaceae and pseudoproteaceous pollen in the Hoodoo and Matanuska Formations. Greisbach (Magoon *et al.*, 1980) identified one species of *Cranwellia,* three species of *Aquilapollenites,* one species of *Wodehouseia,* and "*Proteacidities* species" **(Table 6)** in the Kaguyak Formation. No macrofossils have been reported from these sites. The paleoclimate in this region, inferred from the presence of pollen species of *Proteacidites, Aquilapollenites, Wodehouseia,* and *Cranwellia* **(Table 10)**, was warm, subtropical to tropical.

Description and importance of interior Alaska formations coeval with the Matanuska Formation

Geologic units of the Cantwell Basin. The western and eastern segments of the Alaska Range, with their predominantly rhyolitic volcanoes, outline the Late Mesozoic southern continental edge of Alaska (Csejtey and St. Aubin, 1981; Grantz, Pers. comm., 1995; Ridgway *et al.*, 1997). Prior to emplacement of the McKinley Plutons during the Tertiary (Lanphere and Reed, 1973; West, Pers. comm., 1995), a nonmarine basin, the Cantwell lowland, **(Fig. 12)** occupied the region between the western and eastern sections of the Alaska Range. Today this basin is delimited by two strands of the Denali Fault System, the Hines Creek strike-slip fault on the northern margin and the McKinley strike-slip fault on the southern margin of the basin (Wahrhaftig *et al.*, 1994). The general trend of overland sediment transport and fluvial deposition through the Cantwell lowland during the Late Cretaceous was southward toward the continental margin (Hickman, 1974; Hickman *et al.*, 1977, 1990). Flysch deposits represent floodplains with local lacustrine deposits and numerous river systems (Csejtey *et al.*, 1992), which ultimately prograded toward the Matanuska Seaway.

The Cantwell Formation is nearly as complex in lithology and structure as the Matanuska Formation. The Lower Cantwell Formation is Campanian-Maastrichtian in age (Ridgway *et al.*, 1997). The upper unit, previously known as the Teklanika Volcanics (Gilbert *et al.*, 1976), was described as Tertiary by Bultman (1972) and others (Sherwood, 1973; Hickman, 1974; Gilbert *et al.*, 1976) based on potassium-argon age determinations. More recently, the Teklanika Volcanics has been renamed the Upper Cantwell Formation (Panuska and Macicak, 1986). Cole *et al.* (1999) reported using $^{40}Ar/^{39}Ar$ to establish the age of the Upper Cantwell Formation as 60 to 54 M.y.

Csejtey *et al.* (1992) have tentatively identified several additional outcrops of the Lower Cantwell Formation south of the Denali Fault System, outside of the Cantwell Basin. These rocks crop out in the northern Talkeetna Mountains, approximately 120 km (75 miles) north of the Mazuma Creek study site, described herein. Ridgway (Pers. comm., 1994) stated that he has located a remnant of a marine incursion at the very top of the nonmarine Lower Cantwell deposits, and believes this onlap may be the very northernmost expression of the Matanuska Formation (Ridgway *et al.*, 1997).

The earliest work on the Cantwell Formation paleoflora was compiled by Moffit and Pogue (1915). They collected fossil plant leaves from an outcrop on Wells Creek, approximately 10 miles east of the confluence of the Jack River with the Nenana River. The fossils **(Table 11)** were studied by U. S. Geological Survey paleobotanists Stanton and Hollick, who suggested an Eocene age for the Cantwell Formation, although they noted that Alfred Brooks (1911) believed that fossil leaves he had found in the same area were "older than Tertiary." During the summer of 1936, Capps (1940) escorted Dr. Ralph Chaney to the same area from which Moffit and Pogue had previously collected fossil plant material. Chaney made a collection of eight fossil leaf taxa which he recognized as Late Cretaceous (Capps, 1940). Imlay and Reeside (1954) reviewed Dr. Chaney's fossil plant materials **(Table. 12)** and stated that, rather than Eocene in age as Stanton and Hollick suggested, the Cantwell paleoflora is more characteristic of other Cretaceous flora of Alaska, including the Chignik, Melozi, Nulato, and Kaltag paleofloras. Wolfe and Wahrhaftig (1970) reexamined Chaney's paleobotanical collection and reassigned the Cantwell to the Paleocene **(Table 13)**. Most recently, in a study of the paleopalynology of the Lower

Table 11

A partial listing of the Cantwell paleoflora described as Paleocene-Eocene by Moffit and Pogue
(from Moffit and Pogue, 1915)

Angiosperms

Populus arctica
Aspidium heerii
Daphnogene kanii

Gymnosperms

Taxodium spp.
Sequoia langsdorfii
Ginkgo adiantoides

Cantwell unit, Sweet (1994a, 1994b) reported the presence of an *inland flora* (present author's emphasis) of angiosperms, represented by an abundance of *Aquilapollenites* spp., and stated that the Lower Cantwell Formation is Late Cretaceous (Campanian to Maastrichtian) in age.

Lower Yukon River Basin units. From the mid-Jurassic to the early Late Cretaceous, the sea invaded the lower Yukon River region, encroaching inland as far as the present day Kaltag-Nulato-Melozi (KNM) area **(Fig. 12)** and depositing marine sandstone and shale. Regression of marine waters began in the early Late Cretaceous, and subsequently coal beds formed along the continental margin

Table 12

A listing of the Cantwell paleoflora collected and described as Late Cretaceous by Chaney
(from Imlay and Reeside, 1954)

Angiosperms

Populites mirabilis
Castaliites ordinaries
Crednaria inordinate
Pseudoprotophyllum dentalum
Zisyphus electilis

Gymnosperms

Conifers
Cephalotaxopsis microphylla laxa
Sequoia obovata
Podozmites lanceolatus

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on top of the older marine sediments. Nonmarine sediment containing fossil plant fragments was deposited in side valleys as far inland as the Koyukuk and Kuskokwim Valleys (Hollick, 1930).

Nonmarine Upper Cretaceous deposits are exposed in the Kaltag-Nulato-Melozi (KNM) region along the lower Yukon River between the Brooks Range and the Alaska Range (Hollick, 1930). The most complete section is located near Melozi. Non-marine deposits in this area are considered part of the Yukon-Koyukuk Basin, and radiometric dating indicates an Albian to Turonian age (Patton and Moll-Stalcup, 1996).

Table 13

A listing of the Cantwell paleoflora collected by Chaney, 1936, re-identified and re-named as Paleocene by Wolfe and Wahrhaftig, 1970
(from Wolfe and Wahrhaftig, 1970)

Angiosperms

Cissus sp. aff. *C. marginata*
Cocculus flabella
Dicotylophyllum flexuosa
Grewiopsis auriculaecordatus
Planera microphylla
Sparganium antiquum

Gymnosperms

Glyptostrobus sp.
Metasequoia occidentalis

Early U. S. Geological Survey records show that Russell (1890) explored the entire length of the Yukon River **(Fig. 2)** and collected the first Cretaceous plant fossils from that region. Dall (1896) later collected several specimens near Nulato on the lower Yukon. Knowlton evaluated a collection of plant fossils Spurr (1900) collected near Melozi, on the Yukon River above Nulato. Schrader (1900) brought back plant fossil material from the Chandlar (Chandalar) River, in eastern Alaska, and from the Koyukuk River which empties into the Yukon just above Nulato. Knowlton also evaluated and reported on these collections (Schrader, 1900). While Collier (1902) was

documenting coal resources along the Yukon, he collected a small suite of fossil plants and gave them to Knowlton and Hollick to study. In 1903 Hollick (1930) did his own reconnaissance of the Yukon. During the summer of 1907 Atwood made further collections near Melozi and Nulato (Hollick, 1930). While making assessments of coal resources along the Yukon River, Eakin (1916) confirmed the Cretaceous age of the extensive outcrops along the banks of the Yukon River from Melozitna (Melozi) southward for approximately 12 miles and at a site 10 miles up the Koyukuk River from its confluence with the Yukon, based on fossil plants and invertebrates he collected. Martin (Hollick, 1930) collected plant fossils along the Yukon, and these were added to the growing baseline data.

A large assemblage of early Late Cretaceous fossil plants **(Table 14)** was also collected in the Lower Yukon region by Hollick (1930). This paleoflora is important for two reasons. Hollick (1930) stated that the Late Cretaceous fossil material of the KNM paleoflora represents a unique assemblage of lowland tropical plant species. He specifically noted that three genera, *Nilssonia* (cycad), *Podozamites* (a conifer-like tree), and *Ginkgo* (a non-coniferous gymnosperm tree) are dominant elements in the

Table 14

A partial listing of the Lower Yukon paleoflora
(modified from Hollick, 1930)

Angiosperms
- *Castaliites* sp.
- *Cinnamomum* sp.
- *Ficus* spp.
- *Myrsine* sp.
- *Nymphaeites* sp.
- *Paleonuphar* sp.
- *Paullinia* sp.
- *Platanus* sp.
- *Piper* sp.
- *Sapindus* spp.
- *Sterculia* spp.
- *Zizyphus* sp.

Gymnosperms

Conifers
- *Podozamites lanceolata*
- *Taxodium* sp.

Cycads
- *Nilssonia* spp.

Ginkgo
- numerous spp.

Alaskan and northeast Asian assemblages, and that they "made their last stand in Alaska." He emphasized that *Ginkgo* is represented by nine species in Alaska (two more species than were previously known in all of North America), with eight of the nine species found in outcrops from the Lower Yukon area. Four of the five cycad species found in the KNM paleoflora existed nowhere else on the

North American continent, and five of the six previously known cycad species found in North America were characteristic of Early Cretaceous or older floras. He expressed surprise that *Nilssonia serotina* **(Fig. 18)** is not present in the Yukon assemblages, although the *Nilssonia* genus is represented by other species in the Yukon plant fossil collections. Hollick (1930) recorded that the gymnosperm genus *Podozamites* is "abundantly represented" in collections from Yukon River region, but that "in Cretaceous floras elsewhere it is only sparingly represented."

Hollick (1930) added a most significant reference concerning the cycad *N. serotina* **(Fig. 18)**, which he had expected to find in the KNM region. He stated that *N. serotina*, which he found in abundance in the Campanian-Maastrichtian Chignik paleoflora on the Alaska Peninsula, had previously been recognized as *a coastal paleofloral element of the [entire] Cretaceous north Pacific rim* (present author's emphasis), occurring from Sakhalin northwest of Japan to northwest North America (Kryshtofovich, 1918). Vakhrameev (1991) confirmed that *Nilssonia* species were common all along the North Pacific coastal plain from Sakhalin, Japan, and Alaska to western

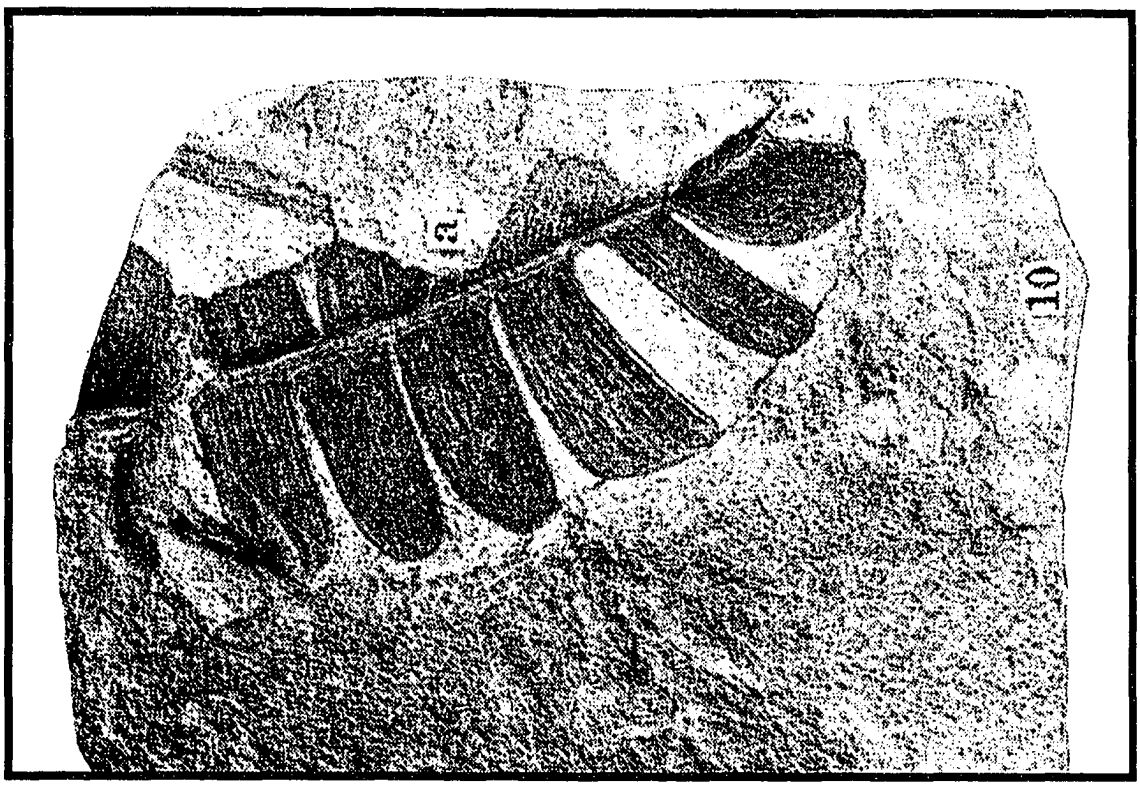

Fig. 18. Fossil leaf of *Nilssonia serotina* (scale unknown). This "coastal cycad" was found on the island of Sakhalin (Kryshtofovich, 1918), in the Chignik (Hollick, 1930), and Nanaimo (Bell, 1957) paleofloras (modified photo from Hollick, 1930).

Canada. Hollick also stated that

> the earlier flora of the Yukon Valley region was ... more tropical in its facies than the later flora of the Alaska Peninsula region ... [and] that arid conditions could not have prevailed ... [as] the presence of ponds or rivers and swamps is indicated by

species of *Taxodium* [bald cypress], *Castaliites* [angiosperm tree], *Nymphaeites* and *Paleonuphar* [water lilies].

Yukon Tanana Uplands units. Two small nonmarine basins in the Yukon Tanana Uplands, to the east of the KNM sites in central eastern Alaska **(Fig. 12)**, contain Maastrichtian non-marine sediments. One basin is located near Chicken, Alaska (Foster and Igarashi, 1989), and the other is near Eagle, Alaska (Tschudy, 1969). Both currently empty into the Yukon drainage.

The sedimentary sequences in these basins were laid down in lacustrine environments and fluvial systems and lie unconformably over igneous and metamorphic rocks of Jurassic age (Foster, 1976). Deposits in both basins commonly contain Late Cretaceous fossil plant fragments, including some *Metasequoia* leaf fragments (Tschudy, 1969; Foster and Igarashi, 1989). Palynological data date the basins as Maastrichtian. The dominant pollen genera in assemblages from these two basins are *Aquilapollenites* and *Cranwellia* (Foster and Igarashi, 1989). The dominance of *Aquilapollenites* Group species invites comparison with *Aquilapollenites*-dominated assemblages, which Frederiksen (1987) associated with arid regions (Wolfe and Upchurch,

1987), supporting the interpretation of an arid Interior Alaska during the Late Cretaceous.

Description and importance of two northern Alaska units in the Colville Basin, Arctic Alaska Terrane, coeval or partially coeval with the Matanuska Formation

The Arctic Alaska Terrane extends from the south flank of the Brooks Range north to the Arctic Coastal Plain (Moore *et al.*, 1994) **(Fig. 12)**. This Terrane is separated from the Wrangellia Composite Terrane by intervening terranes and lay approximately 600 km (372 mi) north of the Matanuska Formation during the Cretaceous (Stone, Pers. comm., 1995). Paleomagnetic data place the Late Cretaceous continental margin of the Arctic Alaska Terrane at approximately 85° N, nearly 15° farther north than its current position (Witte *et al.*, 1987; Besse and Courtillot, 1991).

The Colville Basin is located between the northern flanks of the Brooks Range and the Arctic Coastal Plain (Moore *et al.*, 1994). During the Cretaceous, fluvial systems of the Colville Basin drained into the Arctic Ocean, as they do today (Stott *et al.*, 1993). The Arctic Ocean also received drainage from the northernmost CWIS during the Late Cretaceous **(Fig. 10)**.

The oldest deposits of the Colville Basin are Jurassic. By Early Cretaceous time the basin had partially filled, from west to east, with prograding deltas. The two Cretaceous units in this basin, which range in age from Albian to Maastrichtian (Moore *et al.*, 1994), are referred to in this paper as the Nanushuk and Colville Groups. However, Mull *et al.* (2003) recently revised the nomenclature for Cretaceous and Tertiary geologic units of the central and western North Slope **(Figs. 19 and 20)**. The Colville Group has been abandoned and the Nanushuk Group has been demoted to formation status (Mull *et al.*, 2003). Mull *et al.* (2003) have incorporated six formations, the Kukpowruk, Tuktu, Grandstand, Corwin, Chandler and Ninuluk, into the newly designated Nanushuk Formation, and replaced the Colville Group with the Seabee, Tuluvak, Schrader Bluff, and Prince Creek formations. The newly designated Prince Creek Formation now consists of the former Kogosukruk Tongue and the lower part of the Sagwon Member of the Sagavanirktok Formation **(Figs. 19 and 20)** and is characterized as a nonmarine sandstone, conglomerate and interbedded coal-bearing mudstone (Mull *et al.*, 2003). Of all the nonmarine Cretaceous deposits in Alaska, those in the Early Cretaceous Nanushuk Formation (formerly the

Nanushuk Group) and the Late Cretaceous formations, the Seabee, Tuluvak, Schrader Bluff, and Prince Creek formations (formerly the Colville Group) **(Figs. 19 and 20)** have been most extensively studied because of their oil and gas potential. Thus they are far better understood than all other Cretaceous deposits in Alaska (Wahrhaftig *et al.*, 1994).

Nanushuk Formation. Prior to revision, the Nanushuk Group, now the Nanushuk Formation, included the nonmarine Corwin and Kukpowruk Formations, and the marine Ninuluk, Chandler, Grandstand and Tuktu Formations, all of which have now been abandoned (Mull *et al.*, 2003) **(Fig. 19)**. The Nanushuk Formation is about 3,000 m (9,800 ft) thick and consists of shallow marine shale which grades upward to fluvial sandstone and paludal shale with numerous intercalated coal beds. The Nanushuk Formation is Albian to Cenomanian in age (Wahrhaftig et *al.*, 1994).

The depositional regime of the Corwin Formation, the Albian to Cenomanian nonmarine unit of the former Nanushuk Group, was that of a coastal plain with two deltas, the Corwin and the Umiat (Smiley, 1969). From Late Albian to Cenomanian, the western Corwin delta prograded eastward and emptied into the Arctic Ocean in the vicinity of Point

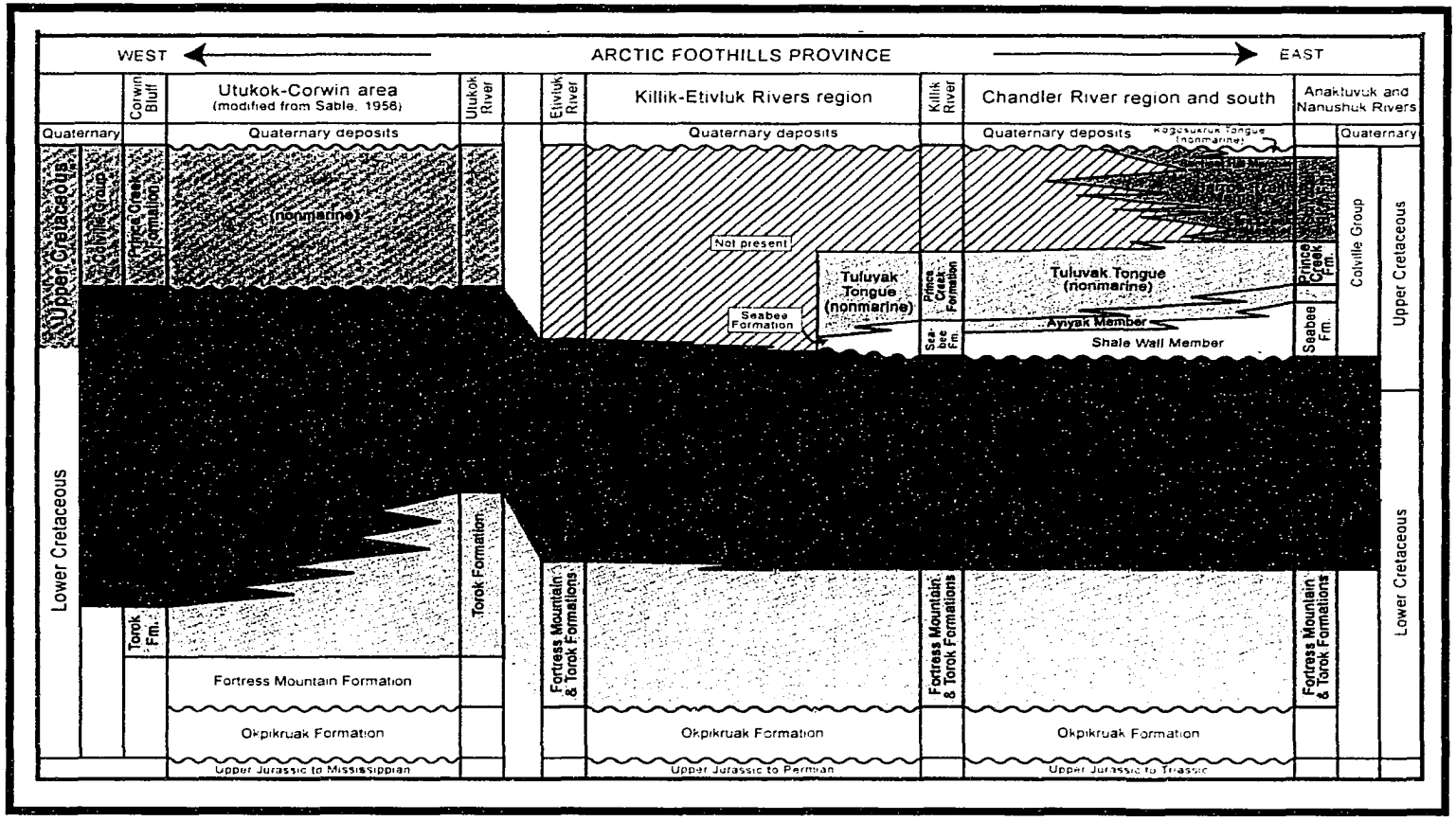

Fig. 19. Revised stratigraphic nomenclature for the Cretaceous and Tertiary geologic units of the central and western North Slope of Alaska. The revised stratigraphic nomenclature on the right is aligned with the older nomenclature, center, by Chapman, Detterman, and Mangus, 1964 (Modified from Mull *et al.*, 2003).

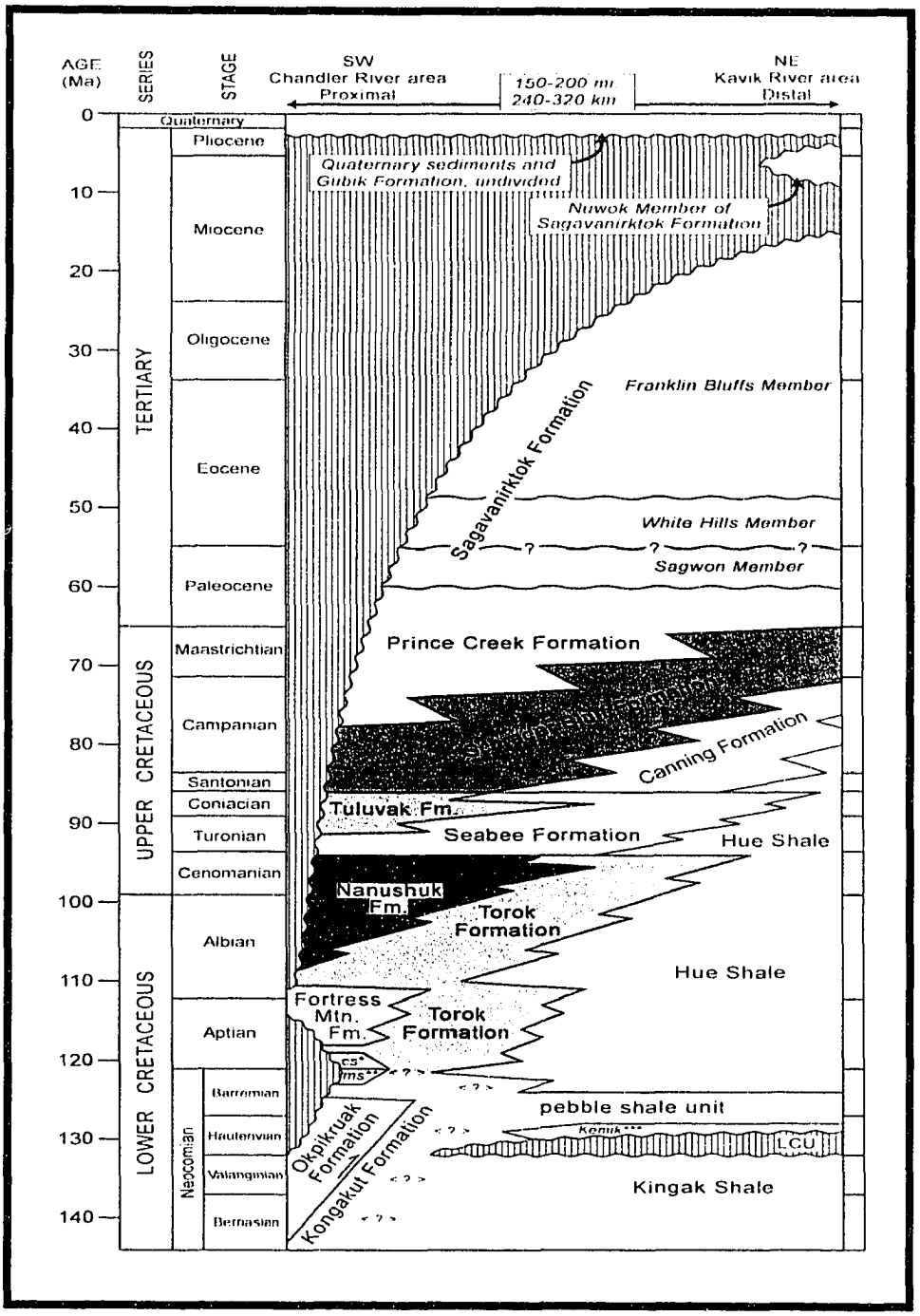

Fig. 20. Stratigraphy of the Cretaceous and Tertiary formations of the Arctic Alaska Terrane. The Fortress Mountain, Torok, Nanushuk, Seabee, Tuluvak, Schrader Bluff, Canning, and the Hue Shale Formations are coeval, and the Prince Creek Formation is partially coeval, with the Matanuska Formation (Mull *et al.*, 2003).

Barrow, Alaska. Swamps were extensive on the fluvially dominated Corwin Delta. During the Cenomanian, the younger Umiat delta prograded northward into the Arctic Ocean from the region of present day Umiat, which is located on the Colville River, approximately 150 km (90 miles) south of the modern Arctic Ocean shoreline (Huffman *et al.*, 1985) and generally southeast of Point Barrow. The Umiat delta system was composed primarily of bays and inland basins. Deposits of both delta systems intertongue with the marine Chandler Formation to the north (Ahlbrandt *et al.*, 1979). Approximately 150 coal seams ranging from 1.7 to 6.1 meters (6 to 20 feet) thick have been identified in the upper Nanushuk Group (Wahrhaftig *et al.*, 1994).

The Corwin Formation contains an abundant fossil record of plant materials, including tree trunks in growth position and leaf fossils representing Cenomanian floras (Smiley, 1966, 1967). Roehler and Stricker (1984) found fossil wood which shows distinct growth rings, implying some seasonality.

May and Shane (1985) studied paleomicrofloras from the Umiat delta and reported 65 genera of spores, representing a diverse fern-lycopod-bryophyte flora growing at sea level on the delta. They also reported 10 genera of bisaccate

gymnosperm pollen in the Umiat assemblages, probably derived from uplands, and a small number of angiosperm pollen. May and Shane (1985) stated that these palynomorph assemblages appear to have been deposited in the Umiat delta "under humid, warm-temperate to subtropical conditions" during the early Cenomanian.

The marine Chandler Formation contains abundant megafloras of Albian and Cenomanian age (Smiley, 1966, 1967, 1969; Scott and Smiley, 1979). Smiley (1966, 1967, 1969) believed these assemblages represent a much warmer climate than that suggested by the younger Cenomanian and Turonian floras of the Corwin Formation.

Prince Creek Formation. The former Colville Group includes the nonmarine Prince Creek Formation **(Figs. 19 and 20)** and two marine units, the lower Seabee Bluff Formation and the upper Schrader Bluff Formation (Brosgé and Whittington, 1966). The uppermost section of the Prince Creek Formation, which intertongues with shallow marine sediment of the Schrader Bluff Formation, is either Turonian to Maastrichtian (Smiley, 1969) or Cenomanian to Maastrichtian in age (Spicer, 1987). The Prince Creek Formation consists mainly of sandstone, conglomerate, shale and coal deposited on an extensive flood plain. Its

fluvial systems drained the ancestral Brooks Range and flowed northward into the Arctic Ocean (Wahrhaftig *et al.*, 1994). The Upper Prince Creek Formation grades into prograding delta deposits of the Tertiary Sagavanirktok Formation (Moore *et al.*, 1994).

Paleoclimate reconstructions based on the Late Cretaceous floras from Arctic Alaska

The Prince Creek Formation contains important Arctic paleomacrofloral assemblages (Smiley, 1969; Scott and Smiley, 1979; Spicer and Parrish, 1986; Frederiksen and Schindler, 1987; Spicer, 1987; Frederiksen *et al.*, 1986, 1988). Numerous data on associated paleomicroflora have been published as well (Smiley, 1966, 1967, 1969; Stanley, 1967; Tschudy, 1969; Wiggins, 1976; Scott and Smiley, 1979; Spicer and Parrish, 1986; Frederiksen, 1987; Frederiksen and Schindler, 1987; Spicer, 1987; Spicer *et al.*, 1987; Frederiksen *et al.*, 1986, 1988; Parrish and Spicer, 1988).

Smiley (1966, 1967) inferred a warm, subtropical paleoclimate for the Cretaceous arctic coastal plane based on the presence of tree ferns in the lower Chandler Formation **(Figs. 19 and 20)**. May and Shane (1985) presented a similar interpretation based on the diversity

of fern, lycopod, and bryophyte spores present in the Albian to Cenomanian age Nanushuk Group sediments of the Umiat Delta **(Fig. 20)**. Stanley (1967) suggested a *"possible latitudinal zonation"* (present author's emphasis) for palynofloras from the Corwin Formation.

Floras from Arctic Alaska provide evidence of long term cooling during the Cretaceous. Smiley (1967) states that the few angiosperms in Late Albian floras are referred to taxa of warm climates. However, rapid climatic cooling from the Late Cenomanian to early Turonian is evident in the fossil flora which lived along the Cretaceous coastal plain (Smiley, 1966). The Middle Albian, Late Albian, and Cenomanian floras are predominantly ferns, tree ferns, ginkgophytes, cycadophytes, and "primitive" conifers (conifers not assignable to extant genera) (Smiley, 1966). By the Turonian angiosperms became dominant elements of the northern Alaska vegetation (Smiley, 1969). Smiley (1966) identified a major change in the character of the Turonian and Coniacian floras and described them as containing abundant angiosperms and "modern" conifers (assignable to extant genera). Campanian taxa from Arctic Alaska are indicative of temperate climates (Frederiksen, 1989).

Smiley (1966) collected an "older [Albian] flora" comprised of a great number of ferns and tree ferns from outcrops of the Chandler Formation **(Fig. 19)** along the Kuk River. He sampled 57 florules (single beds containing plant fossils) in the Corwin Formation, which he interprets as Middle Albian, Upper Albian, Cenomanian, Turonian and Coniacian. Smiley (1966) found numerous plant megaflossils, including wood chips, small logs, tree stumps in growth position, fern fronds, conifer shoots and cones, *Ginkgo* leaves, and compound angiosperm leaves with leaflets still attached to the petiole. He used these elements to reconstruct the Albian to Coniacian environment as a humid, commonly swampy coastal plain. He stated that the presence of the ferns and tree ferns are the basis for his interpretation of a warm climate. He also noted that tree ferns are not found in any of the younger units of Turonian and Coniacian age. However, in their revision of the Nanushuk Group **(Fig. 19)**, Mull *et al.* (2003) stated that

> most of the [Nanushuk] formation is [Middle] Albian and that only the top of the upper part of the formation extends into the Cenomanian**(Fig. 19)**.

Early Albian paleofloral assemblages of the Nanushuk Group **(Fig. 19)** consist of non-deciduous conifers and

cycadophytes, ferns, ginkgophytes and sphenophytes, which were displaced by a rapidly diversifying angiosperm assemblage by latest Albian time (Spicer and Parrish, 1986; Spicer, 1987). Albian-Cenomanian assemblages contain 67 forms of angiosperm leaves, but angiosperm diversity subsequently declined to a very limited assemblage of ten form species by the end of the Maastrichtian (Parrish and Spicer, 1988). Smiley (1967) attributed the decline of angiosperm diversity to a change in the paleoclimate from warm tropical to temperate.

Based on the percentages of entire and serrated margins in leaf assemblages, Wolfe (1979) reconstructed regional paleoclimates by comparing the data to leaf litter from modern plant biomes. He applied the results to data from paleofloral assemblages to reconstruct paleolatitudes **(Table 15) (Fig. 21).**

Using the methods developed by Wolfe (1979), Spicer (1987) interpreted an increase in platanoid-like leaves with serrated margins and an accompanying decrease in entire-margined magnoliid leaves as evidence of progressive climatic deterioration. In addition, Spicer and Parrish (1990) studied fossil wood from the upper member of the Maastrichtian Prince Creek Formation. They concluded that

Table 15

Mean Annual Temperatures and percentage of leaves with entire margins for modern forests
(modified from Wolfe, 1979)

Forest Type	Mean Annual Temperature	Percent Entire Margin
Tropical Rain Forest	$\geq$25°C	>75%
Paratropical Rain Forest	20°-25°C	60-75%
Microphyllus Broad-leaved Evergreen Forest	~13°C	~45%
Notophyllus Broad-leaved Evergreen Forest	13°C	40-60%
Mixed Broadleaf Evergreen and Deciduous Forest	13°C	~41%
Mixed Broadleaf Evergreen and Coniferous Forest,	19°C	30-35%
Mixed Broad-leaved Deciduous Forest	10°C	27-33%
Mixed Northern Hardwood Forest	2.5°C-3.0°C	9-24%
Mixed Coniferous Forest	1°C to -2°C	accessory only
Taiga	1°C to -2°C	0%
Polar Broad-leaved Deciduous Forest	-3.75°C	0%

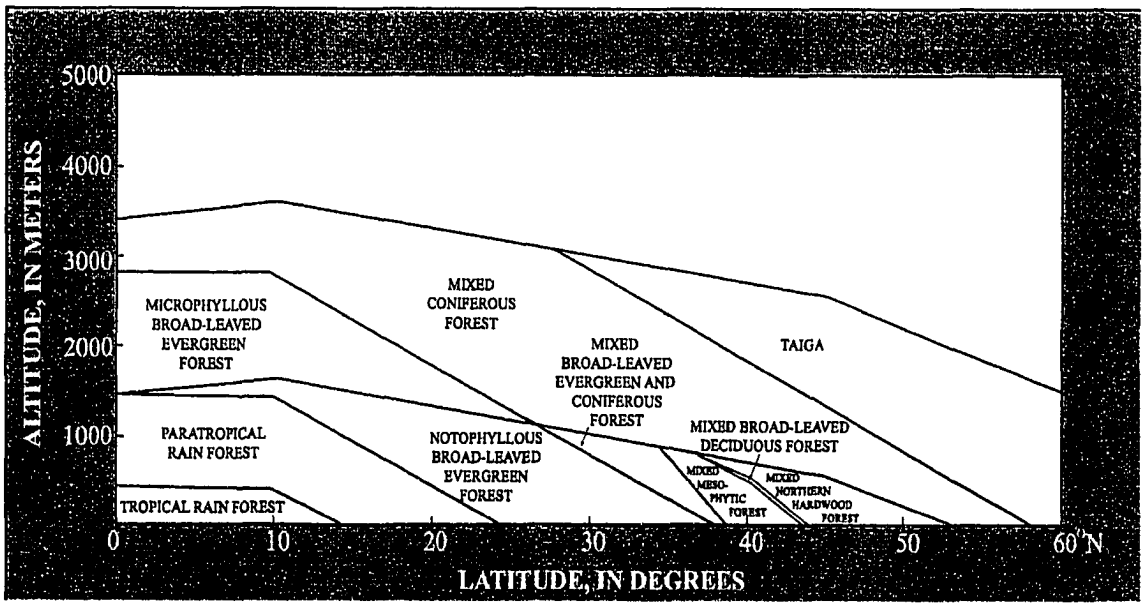

Fig. 21. Latitudinal zonation of modern forests. Simplified altitudinal and latitudinal zonation of modern forests in the Northern Hemisphere (modified from Wolfe, 1979).

narrow growth rings and high ratios of late wood to early wood in the fossil specimens record variable climatic conditions with cool summers.

By the end of Maastrichtian time, northernmost forests of Alaska were composed of a depauperate flora (Spicer, 1987) dominated by toothed platanoid leaves (Spicer and Parrish, 1986), with a complete loss of the smooth-margined magnoliid leaf forms. In addition to deciduous angiosperms, the Late Cretaceous megafloral record includes deciduous gymnosperms (Parrish and Spicer, 1988). Spicer

and Parrish (1986) and Spicer (1987) suggested that deciduousness is evidence for strong seasonality. They initially proposed that this deciduous flora was related to seasonal availability of light, rather than cool temperatures. However, when they used the ratio of serrated leaf margins to entire leaf margins to estimate Mean Annual Temperatures (MAT) **(Table 15) (Fig. 21)** (Wolfe, 1979, 1993; Wolfe and Upchurch, 1987) their results indicate that the MAT increased from 10°C in the Albian to approximately 13°C in the Coniacian, then dropped to between 2° and 8°C in the Maastrichtian (Parrish and Spicer, 1988).

Parrish and Spicer (1988) found macrofossils representing ten angiosperm taxa, including fossil angiosperm leaves, seeds and fruit. They also reported finding coniferous logs and stumps in life position. Frederiksen *et al.* (1987) reported 11 gymnosperm pollen taxa, including at least one taxon of a "*Cedrus* type", in the Maastrichtian Prince Creek Formation. However, Frederiksen *et al.* (1987) found 28 taxa of angiosperm pollen, mostly representing entomophilous (insect pollinated) herbaceous plants as part of the forest understory. Frederiksen (1989) confirmed that the overall diversity of angiosperms decreased throughout

Maastrichtian. He further stated that a decrease in entomophilous angiosperm pollen implies that the lower stories of the forest were progressively simplified toward the end of the Maastrichtian.

More recently, Spicer and Herman (1996) have reported the first occurrences of two species of a vining, deciduous Mesozoic cycad, *Nilssoniocladus*, in the Arctic regions of northeastern Russia and Alaska. This genus of cycad was first reported in the Lower Cretaceous of Japan (Kimura and Sekido, 1975). *Nilssoniocladus* is important to the reconstruction of Late Cretaceous Arctic climates because Herman and Spicer (1997) showed that this plant demonstrates strong frost-resistant habits: rapid and synchronous abscission of leaves and short shoots. *Nilssoniocladus* is present in the Albian of the Corwin Formation of Alaska, and in the latest Albian-Cenomanian of northeastern Russia. Thus, citing the strong frost-resistant habits of *Nilssoniocladus*, Spicer and Herman (1996) stated that "there is no longer any plant fossil evidence for warm to subtropical polar climates" in the Arctic Alaska Terrane during the Albian-Cenomanian.

The palynological record of the Arctic Alaska Terrane also suggests a deterioration of climate during the late

Late Cretaceous. Frederiksen (1989) described the Campanian-Maastrichtian floras, reviewing the macrofossil and microfossil data from the Colville River region. Whereas the fossil megaflora shows no recognizable change during the Campanian-Maastrichtian Epochs, data from 110 angiosperm pollen taxa are indicative of progressive cooling. After identifying and describing five distinct coeval angiosperm pollen groups, 1) *Expressipollis*, 2) Triprojectates, 3) Oculates, 4) Anemophilous (wind pollinated) porates, and 5) other angiosperms, he calculated the turnover rates of these groups. He stated that the pollen groups as a whole exhibit strong evidence of "evolution/immigration and extinction/emigration more or less throughout this time span." In conclusion, he stated that the diversity of angiosperm pollen indicates that the number of angiosperm species was "low in mid(?)-Campanian", increased to a maximum during early Maastrichtian time, and declined during the late Maastrichtian. This decrease in palynofloral diversity represents deterioration of the Arctic Alaska climate during the Maastrichtian (Frederiksen, 1989).

General description of the Campanian-Maastrichtian North Pacific Rim continental margin paleofloras

Western North America. Frederiksen (1987) identified a new Maastrichtian Continental Margin floral province which extends from British Columbia to California. Palynofloras of this province are characterized by the absence or scarcity of taxa belonging to the *Aquilapollenites, Normapolles, and Callistopollenites* pollen groups. *Arecipites* (palm) pollen species, anemophilous (wind pollinated) porate pollen and monosulcate angiosperm pollen are rare or absent. The Continental Margin paleofloras found in the La Panza Range in central California and in the Nanaimo basin, Vancouver Island, British Columbia, are further characterized by abundance of the angiosperm pollen genus *Proteacidites* (broad-leafed evergreens), and the spore genus *Appendicisporites*.

Of particular interest is Frederiksen's (1987) statement that the Continental Margin paleoflora of La Panza may have been *isolated in an offshore setting* (present author's emphasis). The La Panza Range paleoflora extends south from Washington State to the La Panza Range and San Rafael Mountains of coastal central and southern

California. These Late Cretaceous mountain ranges are on the Santa Lucia-Orocopia allochthon, an amalgamation of the Salinian and Stanley Mountain Terranes. The Salinian Terrane is Campanian to Maastrichtian, while the Stanley Mountain Terrane is Cenomanian to Santonian (Frederiksen, 1987).

The Nanaimo Series of Vancouver Island, British Columbia, extends southward to Deming and Bellingham, Washington. Santonian to Maastrichtian in age, its lithology is similar to the lithology of the Matanuska Formation. Sedimentary sequences include conglomerates and coal-bearing nonmarine units intercalated with marine shales. This series overlies the rocks of the Wrangellia Terrane and the Coast Plutonic Complex on the western margins of British Columbia and Washington.

Crickmay and Pocock (1963) discovered the Nanaimo paleomicroflora on Vancouver Island. The flora is dominated by trilete fern spores and *Proteacidites* pollen (Crickmay and Pocock, 1963) **(Fig. 11)**. They stated that the ornamented fern spore genus *Appendicisporites* and the Proteaceae pollen species *Beaupreadites elegansiformis* are present in nearly every sample. The gymnosperm pollen genus *Classopollis* is common in some assemblages, but rare

in others. Tricolpate and triporate angiosperm pollen taxa are "fairly abundant, but no advanced polyporoid types were present." The assemblages are poor in saccate gymnosperm pollen grains (Crickmay and Pocock, 1963). Frederiksen (1987) considered the Nanaimo paleoflora representative of the northern Continental Margin floristic province.

Navarin Basin units. The modern Navarin Basin **(Figs. 11 and 12**) is located on the western margin of the north Pacific Rim, east of the Kamchatka Peninsula, between north latitudes 58° and 63°. The basin, which lies on the submerged Bering Sea shelf, is a large forearc basin containing Campanian-Maastrichtian, and perhaps older, marine and nonmarine sediment (Turner *et al.*, 1985). It is

> bounded by the continental shelf break to the southwest, the Okhotsk-Chukotsk volcanic belt to the east and southeast, and the Anadyr Ridge, a basement high, to the northwest (Turner *et al.*, 1985).

Maastrichtian sediment derived from the Bering shelf and upper bathyal sediment of Campanian age (Turner *et al.*, 1985) lie unconformably on Jurassic volcanic tuffs of the Naknek Formation (McLean, 1979; Vallier *et al.*, 1980). The Maastrichtian unit may represent a western segment of the North Pacific Rim mainland continental margin; it contains

plant and animal microfossils which provide paleoenvironmental information (Turner *et al.*, 1985). An angular unconformity separates Miocene marine sediments and volcanics from the Maastrichtian nonmarine sediments.

Cretaceous sediment occurs in the Navarin Basin COST (Continental Offshore Stratigraphic Test) No. 1 Well at depths of 324 m to 415 m (1,060 ft to 1,360 ft) in the basin section (Turner *et al.*, 1985). Turner *et al.* (1985) said nonmarine sediment, including coal, "probably represent" fluvial and paludal floodplains, are found at depths between 324 m and 387 m (1,060 ft to 1,270 ft). Marine sediment, deposited in outer neritic to upper bathyal paleoenvironments, occurs deeper in the COST No. 1 Well section from 387 m to 415 m (1,270 ft to 1,360 ft).

The nonmarine section of the Navarin Basin is dated as Maastrichtian based on the presence of the pollen species *Aquilapollenites parallelus* and *Mancicorpus* cf. *M. trapeziforme*. The marine unit is dated as Coniacian or Santonian to Campanian based on a single valve of the inoceramid bivalve, *Platyceramus*.

Marine fauna and nonmarine flora were discovered in core samples in the Impenyeyne suite of the Koryak Highlands in eastern Siberia (now the Russian Far East)

(Dundo, 1974; Korotkevich, 1974). These taxa support the theory that the outer Bering Sea shelf stood above sea level during the Maastrichtian (Marlow *et al.*, 1976, 1979). Turner *et al.* (1985) and Jones *et al.* (1981) concur with this theory. Turner *et al.* (1985) report that palynological analyses of Navarin Basin COST No. 1 Well core samples (conventional and side wall cores, and rotary drill bit samples) reveal Cretaceous assemblages similar to those reported by Jones *et al.* (1981) for the Bering Sea shelf margin. According to Jones *et al.* (1981), reworked grains in Bering Sea shelf assemblages include the angiosperm pollen taxa *Aquilapollenites striatus, Aquilapollenites* sp. cf. *A. delicatus*, and *Aquilapollenites reticulatus* which are characteristic of the *Aquilapollenites* Province.

The nonmarine and marine sedimentary sequences of the Navarin Basin represent multiple transgressive-regressive events (Turner *et al.*, 1985). The nonmarine section, 3,896 m to 4,665 m (12,780 ft to 15,300 ft) below sea level of the Navarin Basin COST No. 1 Well, is characterized by non-marine microfossils and macrofossils, coal beds and siltstones representing fluvial-paludal floodplains (Turner *et al.*, 1985). They concluded that the landmass between

the present Russian Far East and Alaska was almost continuously above sea level during the Campanian and Maastrichtian Ages and that the Late Cretaceous terrestrial paleoclimate here was warm temperate and possibly subtropical. Based on the paleomagnetic data derived from conventional cores taken from the Bering Shelf, Van Alstine and Whitney (1984) and Turner *et al.* (1985) further suggested that this region could have been as much as 50° south of its current latitude.

Russian Far East. Zaklinskaia (1962, 1967) distinguished two Cretaceous floristic provinces: the Asian-Pacific province dominated by *Aquilapollenites* and *Proteacidites* genera; and the Atlantic-European province dominated by the Normapolles taxa. On the North American continent the Normapolles Province reaches from the south east to south central United States, and continues across southern Europe to the Ural Mountains of Russia. The *Aquilapollenites* Province extends from the Urals eastward to all of western and northern North American and into northern Europe **(Fig. 1)**.

Rocks in the Russian Far East and Japan are remnants of a subduction zone on the margins of the Cretaceous Proto-Pacific plate and contain rich paleomicrofloral

assemblages. Samoilovich (1967, 1977) and Miki (1977) initially used these assemblages to define paleofloral provinces and subprovinces inland of and along the western Pacific Rim **(Fig. 8)**. Samoilovich (1967, 1977) divided the Russian Far East (from the Lena River eastward to the Pacific) into two "botanico-geographical" provinces: the Khatanga-Lena Province to the north and the Yenisey-Amur Province to the south **(Fig. 22)**.

The northwesternmost boundary of the Khatanga-Lena Province begins at about 90° E on the Arctic Ocean coast. It extends east to the Pacific Ocean and the Okhotsk Sea, with its southernmost margin intersecting the Pacific coast west of the central Kamchatka Peninsula. The southern boundary angles northwest from the Pacific coast to the coast of the Arctic Ocean **(Fig. 22)**. The Yenisey-Amur Province is bounded to the north by the southern border of the Khatanga-Lena Province. The western boundary lies at about 80° east longitude. It is bounded to the east by the Pacific coast, and to the south by Central Asia **(Fig. 22)**.

The Yenisey-Amur Province is divided into three subprovinces **(Fig. 22)**. The northwestern Ust-Yenisey Subprovince faces the Arctic Ocean at its northwestern

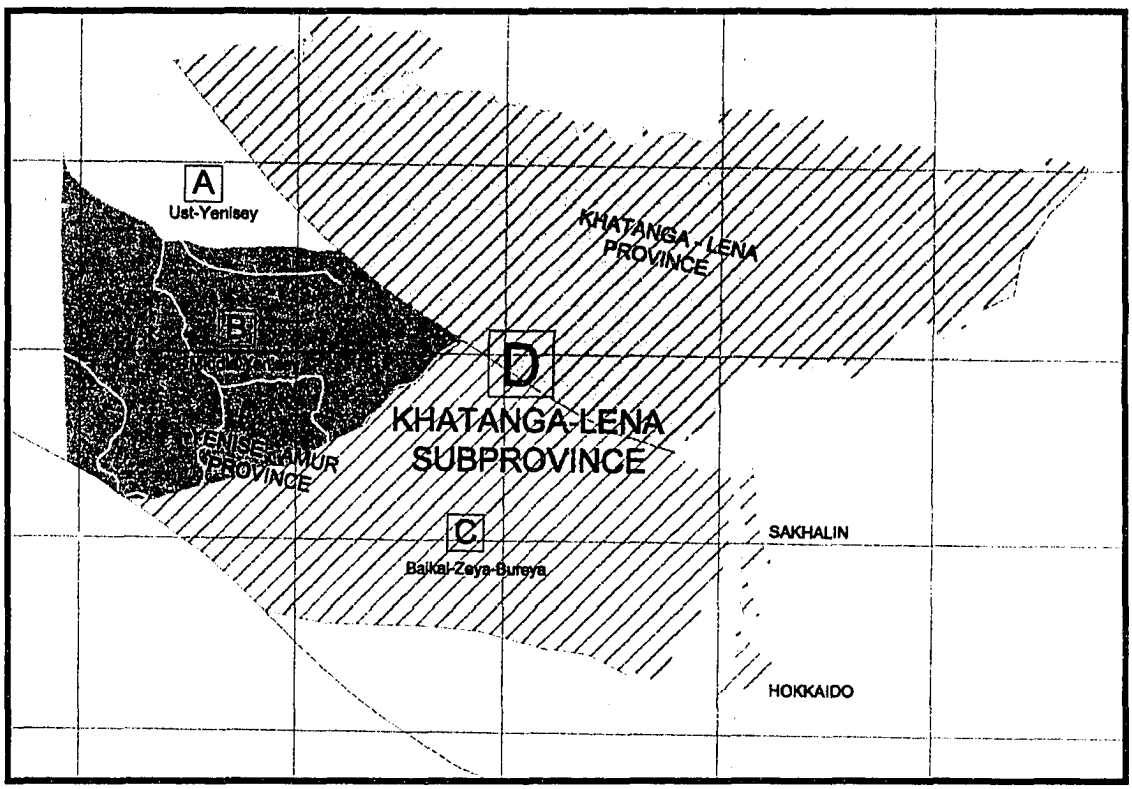

Fig. 22. Location of the Russian Far East. Khatanga-Lena Province is in the north. The southern Yenisey-Amur Province is divided into three subprovinces: A, the northernmost, Ust-Yenisey Subprovince; B, the central, Middle Yenisey Subprovince; and C, the southernmost, Baikal-Zeya-Bureya Subprovince (modified from Samoilovich, 1966). The Khatanga-Lena Subprovince (red hachured lines) includes the older Khatanga-Lena Province and the Baikal-Zeya-Bureya Subprovince (modified from Herngreen *et al.*, 1996).

margin and extends along the southwest border of the Khatanga-Lena Province. The Middle Yenisey Subprovince is positioned to the south and east of the Ust-Yenisey Subprovince, and the southeastern Baikal-Zeya-Bureya

Subprovince (hereafter referred to as the Bureya Subprovince) is flanked by the Ust-Yenisey Subprovince on the west and the Pacific Ocean to the east.

The paleofloral assemblages of the Middle Yenisey Subprovince consist of triprojectates (up to 30%), and a diversity (18 species) of *Proteacidites* pollen (Samoilovich, 1966). The Bureya Subprovince, which includes the southern coastal region, contains a microfloral assemblage dominated by Ulmaceae (20-70%). Samoilovich (1967) stated, however, that tropical and subtropical components of the Proteaceae and other angiosperm families, including Loranthaceae, Symplocaceae, Olacaceae, Nyssaceae, and Palmae, are consistently present in these assemblages. *Cedrus*, a gymnosperm pollen of the Pinaceae family, is also present. She concluded that the assemblages in the Bureya Subprovince are indicative of higher temperatures and humidity than those prevailing at the same time in the Khatanga-Lena Province to the north:

> ...the extensive distribution of the pollen of different species of the [Proteaceae and Loranthaceae Families] (the virtually mass content of *Elytranthe striatus* Couper [*Cranwellia striata* Srivastava])..., [and] the presence of the pollen of other tropical and

> subtropical plants and representatives of the broad-leaved kinds (Fagaceae, Juglandaceae), were evidently due not only to *the fairly high temperatures but also to the higher humidity determined by the proximity to the sea basin* (present author's emphasis).

In comparison, inland assemblages from the northern Khatanga-Lena Province do not include these tropical elements but contain a greater quantity and diversity of the pollen taxa *Aquilapollenites*, *Wodehouseia*, and *Azonia*. Samoilovich (1967) and Herngreen *et al.* (1996) stated that the Khatanga-Lena Province assemblages represent a cooler climatic regime than that represented by Bureya Subprovince assemblages. Thus the Khatanga-Lena Province assemblages indicate a warm, temperate continental climate (Samoilovich, (1967).

Markevitch (1994) reported on Campanian-Maastrichtian paleofloras found along the Pacific coast of Russia from Sakhalin in the south to Chukotka in the extreme north-east. Campanian pollen assemblages from Primorye, Sakhalin **(Fig. 22)**, and from the Bering coal-bearing basin of the Magadan Province, along the north coast of the Okhotsk Sea, contain *Cranwellia striata*, nine species of *Aquilapollenites*, the oculate pollen species *Azonia*

fabacea, and the fern spore *Appendicisporites insignis*. Maastrichtian assemblages from Primorye, Sakhalin, and from the upper Bureya, Zeya-Bureya and Amurozeiskaya Depressions west of Sakhalin, contain four additional species of *Aquilapollenites*, one species of *Mancicorpus*, three species of *Wodehouseia*, one species of *Azonia*, two species of *Proteacidites*, one species of *Cranwellia*, and the Proteaceous pollen *Beaupreaidites elegansiformis*. The increase in number of angiosperm species from Campanian to Maastrichtian suggests a change in paleoclimate as well as introduction and dispersal of new species.

Herngreen *et al.* (1996) have recently reviewed earlier floristic provinces of the Russian Far East, as described by Zaklinskaia (1962, 1967) and Samoilovich (1967, 1977). They distinguished a new geographic subdivision, the Khatanga-Lena Subprovince, considered to be a northeastern subdivision of the Asian *Aquilapollenites* Province. The Khatanga-Lena Subprovince includes the Khatanga-Lena Province and Bureya Subprovince of Samoilovich (1967) and the islands of Sakhalin, Russia, and Japan (Herngreen *et al.*, 1996). The boundaries of the Khatanga-Lena Subprovince are outlined to the north by the Arctic Ocean, to the east by the Okhotsk Sea and the islands of Sakhalin,

Russia, and Japan, to the west by the Ural Mountains, and to the south by Central Asia.

The palynomorph assemblages of the Khatanga-Lena Subprovince are characterized by species of *Aquilapollenites*, *Orbiculapollis*, *Expressipollis*, the *Proteacidites* group, *Wodehouseia* and other oculate form-genera. Assemblages from the Campanian-Maastrichtian Hakobuchi Group, of Hokkaido, Japan, include species of *Cranwellia*, *Kurtzipites* and *Scollardia* (Herngreen *et al.*, 1996). Assemblages of the Khatanga-Lena Subprovince contain subtropical pollen but have a less diverse angiosperm palynoflora than other paleomicrofloras of the *Aquilapollenites* Province.

Hokkaido, Japan. Hokkaido is the largest of the northern islands of Japan. Paleofloras from this island have been analyzed by Miki (1977). The Upper Yezo Group at Saku in northernmost Hokkaido ranges in age from Coniacian to early Campanian (**Figs. 23 and 24**) and is composed of marine siltstone rich in ammonites. The Hakobuchi Group is located inland near the towns of Ashibetsu, Yubari and Hobetsu **(Fig. 23)**. The depositional environment of the Hakobuchi Group, Campanian to Maastrichtian in age (Miki, 1977), is quite similar to that of the Matanuska Formation.

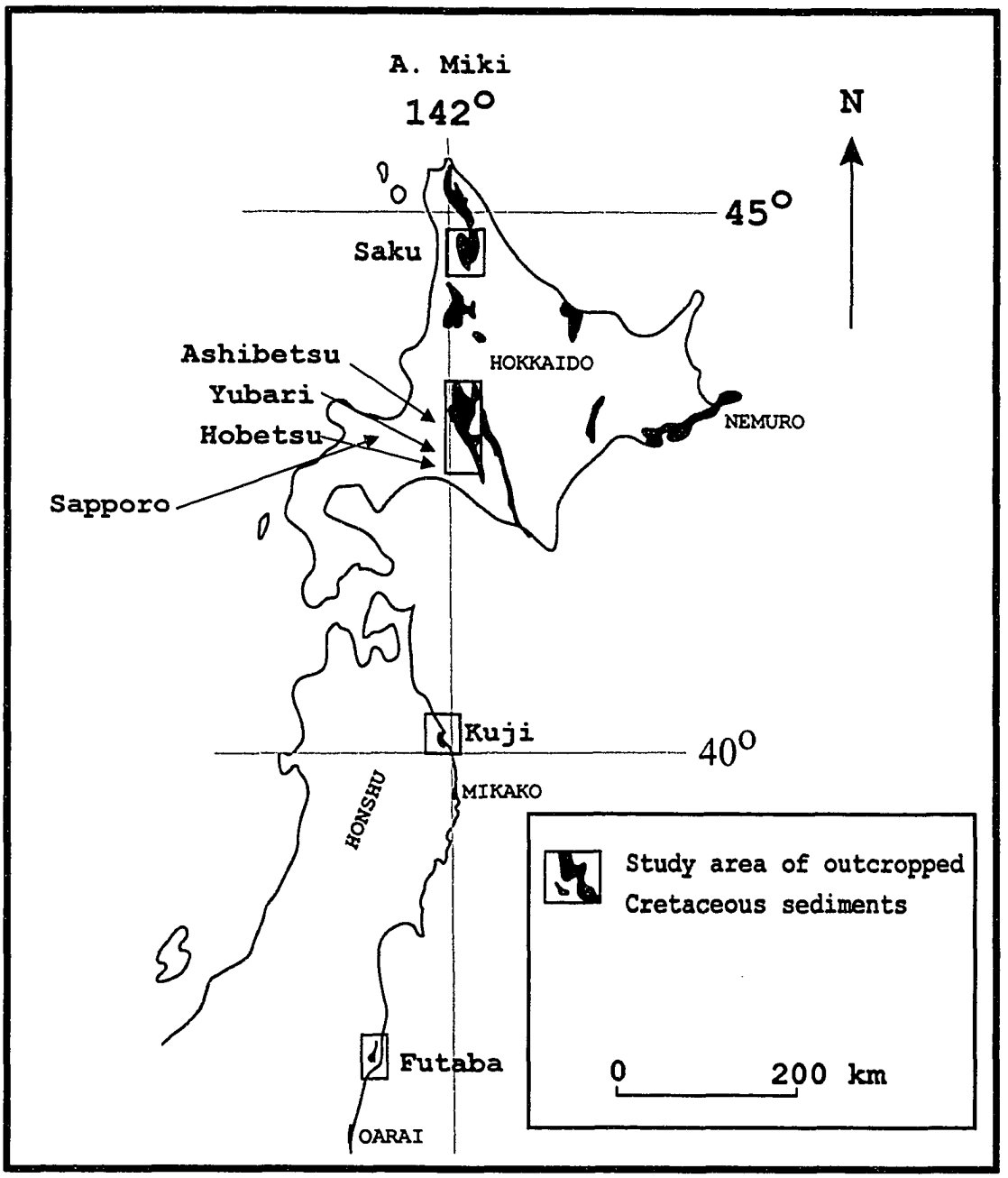

Fig 23. Location map of the Hakobuchi and Yezo Groups, Hokkaido, northern Japan. Sites of the Campanian-Maastrichtian rocks of the Hakobuchi Group are located near the towns of Ashibetsu, Yubari, and Hobetsu. The Yezo Group is located near Saku (modified from Miki, 1977).

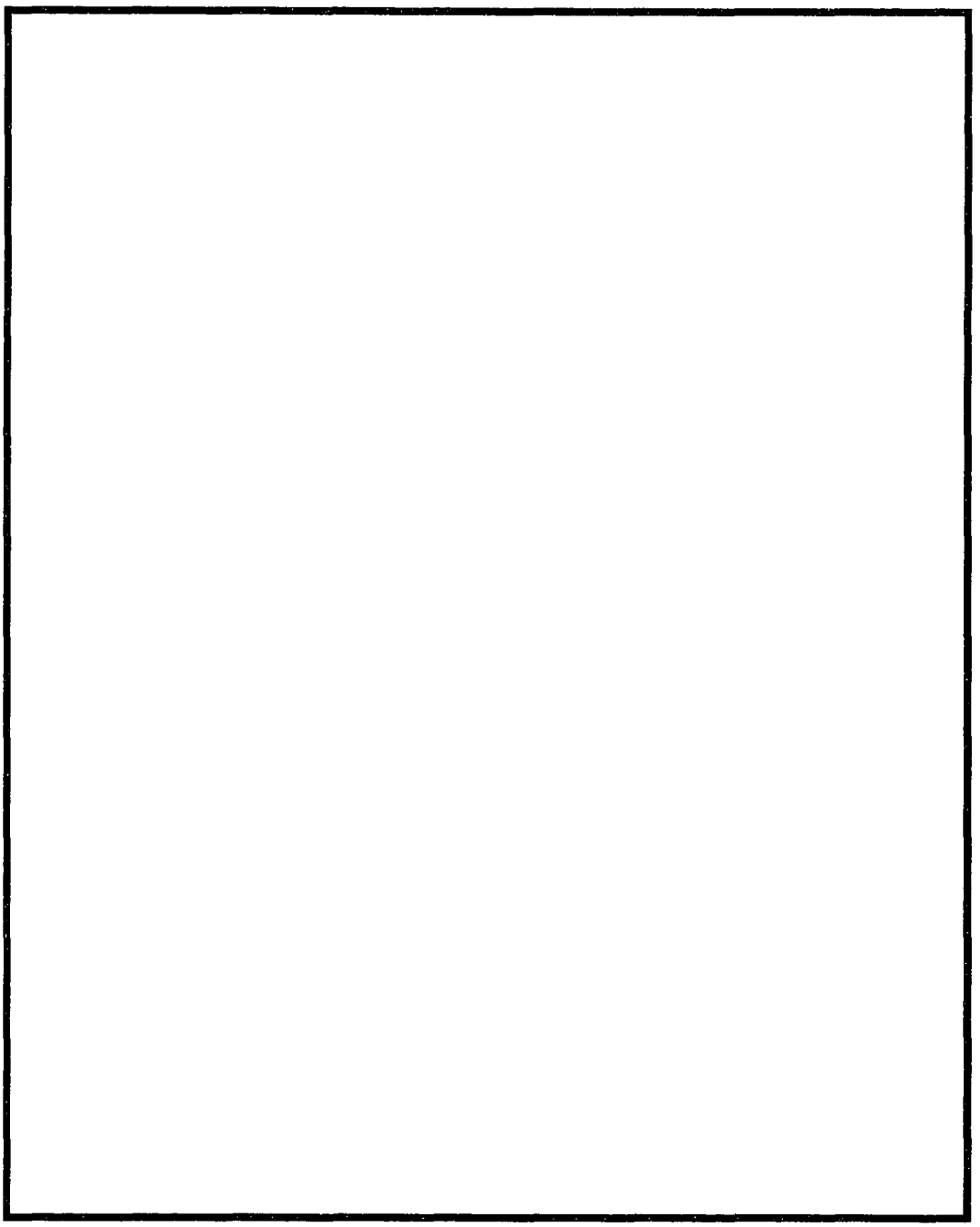

Fig. 24. Stratigraphy of the Hakobuchi and Upper Yezo Groups, Hokkaido, northern Japan. The Hakobuchi Group is Campanian-Maastrichtian in age, and the Upper Yezo Group is Coniacian-Campanian (modified from Miki, 1977).

The Hakobuchi Group is characterized by sequences of conglomerates deposited in a shallow marine environment intercalated with coal bearing units and nonmarine sediment (Miki, 1977). Both the Yezo and Hakobuchi Groups were deposited in a subduction zone on the western margin of Japan during the Hidaka orogeny in the Late Cretaceous (Miki, 1977).

The Upper Yezo Group crops out in the Saku area **(Figs. 23 and 24)** and contains the Kyowa paleoflora. This paleoflora is dominated by 56 species of fern spores and 54 species of angiosperm pollen, including 12 species of *Aquilapollenites* (Miki, 1977). Pollen of the gymnosperm family *Taxodiaceae* and angiosperm genus *Quercus* are also abundant (Sato, 1961; Miki, 1977).

The Yasukawa Formation, found in the Saku area **(Fig. 23)**, contains 12 species of *Aquilapollenites* pollen (Miki, 1977). This angiosperm-dominated assemblage is inferred to be Campanian based on the ammonite and *Inoceramus* species present. Thus it is younger than the Yezo Group and contemporaneous with the lower Hakobuchi Group.

The lower Hakobuchi Group from central Hokkaido contains a Campanian microfloral assemblage which includes 12 species of *Aquilapollenites* and two species of

Podocarpidites, but no species of *Proteacidites*. Overall there are 56 species of ferns, 36 species of gymnosperms and 77 species of angiosperms. Microfloral assemblages extracted from the Maastrichtian upper Hakobuchi Group are dominated by 15 species of *Aquilapollenites*, one species of *Mancicorpus*, two species of *Wodehouseia*, and one species of *Orbiculapollis*. Overall there are 26 species of fern spores, 24 species of gymnosperm pollen, and 63 species of angiosperm pollen. Pollen of Proteaceae and *Cedrus* are not reported (Miki, 1977).

Latest Cretaceous pollen assemblages from the Nemuro Group in eastern Hokkaido **(Fig. 23)** are dominated by Ulmaceous pollen. Three species of *Aquilapollenites* and one species each of *Cranwellia* and *Proteacidites* also are present (Miki, 1977).

Miki (1977) emphasized that, over time, the ferns and gymnosperms in all these assemblages were slowly being replaced by angiosperms. Overall, this suggests that the paleoclimate in this region was cooling throughout the Campanian and Maastrichtian. He also compared the Hakobuchi Group assemblage to the Yenisey-Amur Province of Samoilovich (1966) and concluded that the Maastrichtian Hokkaido paleoflora is more similar to the paleoflora of

the Bureya subprovince, which is bounded on its eastern margin by the western Pacific Ocean, than to the paleofloras of the interior Middle Yenisey subprovince. Similarities include diverse and abundant angiosperms, representing more than half of all palynomorph species.

In a comparison, Miki (1977) stated that the Bureya subprovince angiosperm assemblage is dominated by diverse species of *Proteacidites,* but the number of species is not stated in the report. This dominance is important, because Proteaceous pollen species are characteristic of a warm humid continental margin (Frederiksen, 1987). Miki (1977) only identified one species of *Proteacidites* pollen from Hokkaido in the Latest Cretaceous Nemuro Group assemblage, but supported the comparison by noting that assemblages of the Bureya subprovince contain 19 species of *Aquilapollenites,* while 23 *Aquilapollenites* species are present in the Yasukawa Formation and Hakobuchi Group combined. This is comparable to the numbers of *Proteacidites* and *Aquilapollenites* species recovered from Maastrichtian paleofloras of Arctic Alaska. Thus the paleoflora of northern Japan is similar to the Campanian-Maastrichtian of Arctic Alaska.

Geologic history and paleofloras of the Cretaceous Western Interior Seaway

Relationship of the CWIS to Campanian-Maastrichtian age formations in Alaska. The CWIS existed for a period of approximately 33 million years (Cenomanian to Maastrichtian) (Obradovich, 1993) **(Fig. 10)**. The depositional histories of the Matanuska Formation (Jones, 1963) and Arctic Alaska (Smiley, 1969; Spicer and Parrish, 1986; Spicer *et al.*, 1987) are longer than that of the CWIS, extending from the Albian to the Maastrichtian. The Late Cretaceous Lower Yukon River paleoflora, preserved in rocks of the Kaltag, Nulato, and Melozi Formations, flourished from the Cenomanian to the Maastrichtian (Hollick, 1930) and thus is coeval with the CWIS. However, the Kaguyak, Chignik, Hoodoo (Detterman, 1988; Detterman *et al.*, 1996), and Cantwell formations (Ridgway *et al.*, 1997), and the Chicken (Foster and Igarashi, 1989) and Eagle paleofloras (Tschudy, 1969) of the Yukon-Tanana region are all Campanian-Maastrichtian, or Maastrichtian in age, and therefore are coeval with only the younger deposits of the CWIS.

Geologic history. CWIS deposits are significant because they contain some of the largest gas, oil and coal

deposits in North America, including those on the North Slope of Alaska. Because of these non-renewable resources, the CWIS region has been extensively studied. Although contemporaneous with the Matanuska Seaway, the CWIS is located farther east, along the eastern flanks of the ancestral Rocky Mountain system. Currently, there is no suggestion in the literature of a marine connection between the Matanuska Seaway and the CWIS during the Late Cretaceous.

The CWIS developed as two basins, one on the northcentral Arctic coastal margin and another on the southern gulf coastal margin of the North American continent. Intermittent sea level highstands covered the craton and connected the two basins, producing a continuous intercontinental seaway. The CWIS apparently reached its greatest width and height during the Turonian, followed by a major regression in the early Campanian, during which the CWIS returned to its northern and southern basins. By Campanian time, the entire epeiric seaway was again connected and the rise in sea level continued into the Early Maastrichtian, when the CWIS apparently reached a high stand. At the end of the Late Maastrichtian, worldwide regression eliminated the connection between the

Arctic Ocean and the Gulf of Mexico (Williams and Stelck, 1975; Srivastava, 1978), terminating the epeiric seaway as a marine depositional system and a marine paleoenvironment (Frederiksen, 1989). The depositional record of the CWIS contains a complex and detailed fossil record of nonmarine deciduous paleofloral assemblages.

First occurrence data of age-diagnostic pollen taxa. The CWIS has long been recognized as the barrier between two paleofloristic provinces **(Figs. 1 and 10)**: the Eastern, or Normapolles Province; and the Western, or *Aquilapollenites* Province (Zaklinskaia, 1962). The appearance and disappearance of floral taxa in these two provinces may have been the result of climatic changes (Frederiksen, 1989) which contributed to the demise of the CWIS.

Nichols and Sweet (1993) identified four biostratigraphic zones in Cretaceous deposits of the CWIS, using first occurrences of morphological groups and fossil pollen taxa to delineate biostratigraphic boundaries **(Fig. 5)**. These chronostratigraphic boundaries represent evolutionary development of pollen taxa and are not necessarily coincident with stage boundaries defined by invertebrate fossils (Nichols and Sweet, 1993).

The Albian-Cenomanian boundary is palynologically defined by the first occurrence of tricolporate angiosperm pollen and the regional first occurrence of obligate pollen tetrads. The Turonian-Coniacian boundary is coincident with the first occurrence of the triporate pollen genus *Proteacidites* and the oculate pollen genus *Azonia*. The Santonian-Campanian boundary is recognized by the first occurrence of the morphologically distinctive triprojectate pollen group *Aquilapollenites*. The Campanian-Maastrichtian boundary is denoted by the first occurrence of the pollen genera *Kurtzipites* and *Wodehouseia*. Finally, the base of the Upper Maastrichtian is distinguished by the first occurrences of the pollen species *Wodehouseia spinata* and *Mancicorpus vancampoae* **(Table 2)**.

Geographically endemic pollen taxa. Nichols and Sweet (1993) also reported geographic endemism of Late Cretaceous pollen assemblages along the length of the CWIS. Many of these endemic taxa are also biostratigraphically significant.

> ...pre-Maastrichtian floras of the central Western Interior are uniform in composition for the most part. However, at each end of our north-south transect, taxa are present that are

> not represented at the opposite end of the transect... the genus *Proteacidites* [is] a conspicuous element in the flora in the southern and central parts of the basin but... not... in the Yukon and Northwest Territories [and]... groups present in the Yukon and Northwest Territories... do not extend to the southern extremity of the transect.
>
> Maastrichtian palynofloras of the northern and north-central parts of the basin... occur rarely or never to the south... Diversity of the triprojectate and oculate pollen groups increases toward the north, triporates including Normapolles increase in diversity toward the south.

Thus, during the Late Cretaceous, endemic pollen taxa characterize deposits of the northern, central and southern regions of the CWIS **(Figs. 5 and 10)**. Many taxa that define biostratigraphic zones are also limited in geographic distribution. Obligate tetrads and sculptured tricolporate pollen grains are found in the northern and central regions of the CWIS. *Azonia* appears in the northern regions of the Yukon but does not extend southward

to Alberta, while *Proteacidites* species are found throughout the central and southern regions of the CWIS. *Aquilapollenites* genera appear in northern regions at the Santonian-Campanian boundary, later spreading to the central and southern regions of the CWIS. *Wodehouseia* genera are restricted to the northern and central regions of the CWIS, while *Kurtzipites* genera are found in the central and southern regions of the basin. The triprojectate taxon *Mancicorpus vancampoae* occurs in the northern region of the CWIS, while the oculate taxon *Wodehouseia spinata* has been recorded as the dominant Upper Maastrichtian taxon in the central regions the CWIS. *Aquilapollenites* and *Proteacidites* species are also common in the Upper Maastrichtian deposits of the central CWIS region.

Jerzykiewicz and Sweet (1986) reviewed pollen and spore assemblages of the Coalspur Formation, a CWIS deposit in the Rocky Mountains foothills in Alberta, Canada. They listed biostratigraphically significant pollen and spore taxa of Paleocene age, taxa that span the Cretaceous-Tertiary boundary, and taxa restricted to the Maastrichtian **(Table 16)**. Table 16 contains the lists of Cretaceous-Tertiary and Maastrichtian taxa relevant to this study.

Table 16

Biostratigraphically significant pollen and spore taxa from the Edmonton Formation, Alberta, Canada
(modified from Jerzykiewicz and Sweet, 1986)

Species restricted to Maastrichtian

Aquilapollenites augustus Srivastava 1969
A. conatus Norton 1965
A. delicatus var. *delicatus* Tschudy and Leopold 1971
A. quadrilobus Rouse 1957
Cranwellia rumseyensis Srivastava 1966
Ephedrapites multipartitus (Chlonova) Gao and Zhao 1976
Foraminisporis undulosa Leffingwell 1971
Retibrevitrocolporites beccus Sweet 1986
Striatellipollis stratella (Mchedlishvili) Krutzch 1969
Wodehouseia octaspina Wiggins 1976

Taxa that persist from the Cretaceous to the Early Paleocene

Aquilapollenites reticulatus (Mchedlishvili) Tschudy and Leopold 1972
Betulaceae-Myricaceae *pollen*
Hazaria sheoparii Srivastava 1971
Mancicorpus sp. cf. *M. tripodiformis* (Tschudy and Leopold) Tschudy 1973
Nyssoidites anulatus (Chlonova) Sweet 1986
Penetetrapites inconspicuus Sweet 1986
Ulmoideipites herbridicus (Simpson) Sweet 1986
Wodehouseia spinata Stanley 1961

Paleolatitude reconstructions based on leaf margin analyses

Based on geographically endemic pollen taxa Nichols and Sweet (1993) delineated three *Aquilapollenites*

subprovinces located in the northern, central and southern regions of the CWIS. Nichols and Sweet (1993) recognized that

> most endemics are angiosperms..., [that they exhibit] significant latitudinal variation...within the terrestrial flora of the region... [and that the] data suggest that endemism is greater at the northern and southern extremes of the basin than in the central area.

They designated *Wodehouseia quadrispina*, *W. octospina*, *Aquilapollenites parallelus*, *Triprojectus magnus* and *T. unicus* as pollen species representative of their northern *Aquilapollenites* subprovince. This subprovince, >75° N, corresponds generally to Wolfe's (1979) polar broad-leaved deciduous angiosperm forest north of paleolatitude 70° N **(Table 15)**.

Nichols and Sweet (1993) showed that the southern *Aquilapollenites* subprovince contains angiosperm pollen species including *Tilia wodehousei*, *Thomsonipollis magnificus*, and the angiosperm pollen genus *Arecipites*, all "essentially unknown farther north". These pollen species, found at latitudes <60° N, roughly correspond to Wolfe's (1979) paratropical rain forests **(Table 15)** based on

macrofossils of broad-leaved angiosperm evergreens south of paleolatitude 56° N.

The association of deciduous leaf fossils (Wolfe, 1979) with angiosperm pollen assemblages (Nichols and Sweet, 1993) in the northern *Aquilapollenites* subprovince introduces the possibility that the plants which produced *Aquilapollenites* and *Wodehouseia* pollen species at >75° N may have been deciduous. The recognition of different pollen taxa from north to south (Nichols and Sweet, 1993) along the coast of the CWIS also suggests that Mean Annual Temperatures during the Late Cretaceous varied from very cool in the northern *Aquilapollenites* subprovince, which was rich in deciduous angiosperms, to tropical warm in the southern *Aquilapollenites* subprovince, which was rich in pollen species derived from broadleaf angiosperm evergreens **(Table 15)**.

Paleomicrofloral elements of Cretaceous tropical and subtropical floras found in the Matanuska paleoflora

The *Aquilapollenites* Group is the signature angiosperm pollen type in the *Aquilapollenites* Floral Province. According to studies by Rouse and Srivastava (1972), two common *Aquilapollenites* Group taxa, *Aquilapollenites* and

Mancicorpus, in association with *Beaupreadites* of the Proteaceae Group and *Cranwellia* of the *Callistopollenites* Group **(Table 1)**, represent subtropical vegetation. Jerzykciewicz and Sweet (1986) considered the pollen genera *Aquilapollenites* and *Mancicorpus*, along with *Wodehouseia*, *Ilexpollenites*, *Nyssapollenites*, *Nyssoidites*, and *Proteacidites* to be representative of a humid subtropical environment.

Fern spore genera and gymnosperm pollen from the *Aquilapollenites* Province also imply a warm, humid subtropical environment. Taylor and Taylor (1993) described the fern which produced the spore genus *Gleicheniidites* as a major element of ancient tropical swamps, living in a single stand or in mixed vegetation. Srivastava (1970), reporting on the paleoflora in the Edmonton Formation, emphasized the tropical rainforest character of primitive Proteaceae. He also noted that the presence of the fossil pollen genera *Sequoiapollenites* and *Taxodiaceaepollenites* "suggest a swampy locality" along the shoreline of the approaching CWIS.

The Normapolles Province **(Fig. 1)** is home to over 60 genera of Normapolles pollen. Twenty-six Normapolles genera have been recognized in the Atlantic Coastal Plain

region and 19 in the Gulf Coast area of the United States (Herngreen *et al.*, 1996). Paleoclimate reconstructions for this province are based primarily on studies by Wolfe and Upchurch (1987) and Upchurch and Wolfe (1987) who describe leaf, fruit and seed assemblages from the eastern United States. Large volumes of parenchyma in the tree wood, small thick leaves and the absence of distinct growth rings are indicative of a climate without freezing temperatures. The inferred climate for the Normapolles Province is thus subtropical to warm temperate and humid-wet (Herngreen *et al.*, 1996).

The *Glossopteris* Flora evolved during the Late Paleozoic (Takhtajan, 1969) as a boreal flora around the margins of continental glaciers centered over the Southern Polar region (Douglas and Williams, 1982). This distinctive flora included lycopods, ferns, seed ferns, cycads, southern conifers including Podocarpaceae, and later in the Mesozoic, early angiosperms, especially the Proteaceae (White, 1990). By the end of the Paleozoic, gymnosperm adaptations such as deciduousness, efficient root systems, reduced leaves that conserved water, and rapid seed production had appeared, rendering this flora more suited to a cold-dry environment (Takhtajan, 1969).

These adaptive characteristics were also successful in the warm-dry environments of the Mesozoic (White, 1990).

After the southern ice age ended in the Late Permian, Australia and India remained connected, and many members of the *Glossopteris* Flora were dispersed northward into Asia. Some species eventually reached the Arctic (Takhtajan, 1969).

Takhtajan (1969, 1991) stated that angiosperms and gymnosperms of the *Glossopteris* Flora were successfully dispersed throughout the globe from ancestral Australia, adapting to many environments. He considered east and south-east Asia, Australasia and Melanesia the probable cradle of angiosperms, because the greatest number of structurally primitive angiosperm wood specimens and reproductive organs are found in that region. Axelrod (1952) supported this concept, stating that the most primitive living species of angiosperm hardwood trees, maple, poplar, birch, oak, cherry and hackberry, are largely evergreen types found in warm temperate to tropical regions. He further claimed that the deciduous habit of these trees is a derived characteristic that evolved later at high latitudes.

Takhtajan (1969) suggested that angiosperms appeared during the early Jurassic, but that their dispersal and differentiation did not occur until the Early Cretaceous. He also stated that the differences between tropical and temperate angiosperm floras were "already manifest" by the Late Cretaceous, and that the Boreal and Tethyan "phytogeographical regions were distinctly outlined", or established, by that time (Takhtajan, 1969). The Boreal-Cretaceous region occupied a vast expanse of land including northern Europe, Kazakhstan, Siberia, the Russian Far East, Japan, Korea, part of North America and the Arctic. The Tethyan-Cretaceous region included southern Europe, the Caucasus, and central Russia to Mongolia and north China (Takhtajan, 1969).

Evergreen tropical forms of the angiosperm family Proteaceae are a significant component of the *Glossopteris* Flora believed to have evolved in southeastern Australia by Campanian-Maastrichtian time. Proteaceous forms (trees and shrubs with large, leathery, entire margin leaves and large compact inflorescences) and sclerophyllic forms (shrubs with small, thick leaves), are known to have lived in both sclerophyll communities, which have no modern analogues, and rain forests (Dettman and Jarzen, 1991).

Some disagreement exists as to the lineage of the North American Proteaceae Family. Frederiksen (1987) noted that pollen produced by this family is considered by some to be

> morphologically different both from modern pollen of the family Proteaceae and from the pollen genus *Proteacidites sensu stricto*, whose type species is from the Southern Hemisphere.

One recent suggestion is that the "*Proteacidites*" pollen group of North America, although similar to Proteaceous pollen of the Southern Hemisphere, is more closely related to the Symplocaceae pollen family (Rouse, 1962; McLeroy, 1971; Martin and Harris, 1974) because of the very similar "pore structure, surface pattern, shape and size of some species, particularly *Symplocos stawelli*" (Memon, 1983). Nevertheless, latest Cretaceous pollen grains in northern South America have been assigned to the genus *Proteacidites* (Germeraad *et al.*, 1968).

Johnson and Briggs (1975) provided a solution to this conflict in their review and discussion of the complex chromosomal evolution and early polyploidy of the Proteaceae. Changes have occurred in "nearly all" the characters, "mostly as adaptations to environment,

including response to fire and vegetative reproduction" (Johnson and Briggs, 1975). They concluded that the ancestral Proteaceae diversified before the breakup of Gondwanaland and were then isolated as the continents rafted apart.

The Proteaceae inhabited the same environments as the southern conifers, the Podocarpaceae (Johnson and Briggs, 1975), which are well-known elements of the Mesozoic Gondwanaland flora. The microfossil record shows that only a limited number of *Podocarpidites* pollen species are represented in the northern hemisphere (Dilcher, 1969; Wiggins, 1988; Taylor and Taylor, 1993). Thus, it is likely that only a small number of *Podocarpidites* pollen species will be found in association with Proteaceous pollen in Late Cretaceous palynofloras of Alaska.

Metasequoia, known today as a "living fossil" (Merrill, 1948), is a genus of deciduous coniferous gymnosperms. This genus was initially described by Japanese paleobotanist Shigeru Miki in 1941 on the basis of fossil material (Miki, 1941). At that time, he transferred several fossil leaf species previously assigned to *Sequoia* to the new genus. Concurrently, Dr. T. Kan of the Department of Forestry of the National Central University,

China, discovered the first known living specimen of *Metasequoia* while traveling in the Szechuan Province. Eventually, more than one hundred of these trees were found near 31° N in the Szechuan Province, where the climate is very wet with occasional frost and snow (Merrill, 1948; Fulling, 1976).

In the Mesozoic fossil record, *Metasequoia* has been associated with an overall summer-wet (mesic), rather than summer-dry, regime (Chaney, 1951). Fulling (1976) reported that the region in which the living *Metasequoia* trees were found "is a region of considerable rainfall." This suggests that the climate of the Szechuan Province regions is similar to the mesic climate in which *Metasequoia* lived during the Mesozoic. Fulling (1976) also pointed out that the common local name for the *Metasequoia* is "water fir."

These Gondwanan floral elements are present in the Late Cretaceous palynofloras of the Matanuska Formation. Pollen grains record the presence of the families Proteaceae (evergreen angiosperms) (Wiggins, 1988), Podocarpaceae (evergreen conifers), Taxodiaceae (*Metasequoia*, *Sequoia*, bald cypress and yew family), and other gymnosperms from the orders Cycadales (cycads) and Ginkgoales (*Ginkgo*). Some species of ferns, tree ferns and

lycopods known from Alaska also have Gondwanan origins (Taylor and Taylor, 1993).

Deciduous characteristics in plants, including the *Aquilapollenites* Group, that suggest arid, cool paleoclimates and seasonality in Arctic and Interior Alaska during the Campanian-Maastrichtian

Two characteristics of Late Cretaceous plant assemblages of the Arctic Alaska Terrane, annual rings of light and dark wood and the deciduous habit, are adaptations to stressful seasonal changes in temperature and/or light availability.

Dendrochronology, the study of growth in woody plants, is used to determine whether annual growth rings are present in the cellular structure of wood. If an alternation of dense (dark wood) and less dense light wood growth rings is not present, available light and moisture are interpreted as relatively constant (Douglass, 1916). Where rings are present, the wider, less dense bands indicate faster growth due to warmer seasonal temperatures or increased moisture availability, while more dense rings suggest slower growth due to cooler temperatures, drier atmosphere, reduction of light availability, or any combination of these stressful conditions (Wolfe and

Upchurch, 1987). Density variations in the wood thus suggest that seasonal light and temperature regimes are in operation (Huntington, 1914; Stokes and Smiley, 1968). Furthermore, the ratio of dark wood to light wood demonstrates the relative durations of the alternating seasons (Spicer and Parrish, 1990).

Deciduousness, another adaptation to seasonality, is characterized by the dehiscing, or breaking off, of leaves at the base of their stems, or petioles, from branches at the end of the growth season. This process conserves plant resources in a climate that would otherwise demand excessive energy to maintain leaves on a year-round basis by a timed chemical response to decreasing sunlight (Stokes and Smiley, 1968).

Axelrod (1952) wrote that the most primitive living species of deciduous angiosperms

> frequently regarded as temperate, such as *Alnus* (alder), *Acer* (maple), *Betula* (birch), *Crataegus* (haw), *Cercidiphyllum* (katsura), *Liquidambar* (sweet gum), and *Platanus* (sycamore), are largely evergreen and found in warm temperate to tropical regions.

Axelrod (1966) later stated that the deciduous habit was "the adaptive response of many tropical woody plants to

drought" in tropical and subtropical regions, and that this induced dormancy was not "*in response to photoperiodicity at high latitudes*" (present author's emphasis in italics). Wolfe (1987) concurred that the deciduous characteristic "is one of the most important adaptations of woody plants to climates that have periods unfavorable to growth." Spicer and Parrish (1986) noted that "deciduousness is evidence for strong seasonality" and that

> cool temperatures are suggested by the prevalence of toothed leaves among the [deciduous] angiosperms and the presence of large-leaved conifers.

McIver *et al.* (1991) reported the recent discovery, in the Ravenscrag Butte Formation in southeastern Saskatchewan, Canada, of three relatively complete fossil flowers of *Kurtziflora antherosa* (Basinger, Pers. comm., 2006) which contain abundant pollen. McIver *et al.* (1991) described the best preserved fossil flower of the 65 million year old flowering plants (University of Saskatchewan Paleobotanical Collection specimen US30-3309-1) **(Fig. 25)**, as

> nearly 5 mm (0.2 inch) long and 6.00 mm (0.24 inch) in diameter, globular to subglobular with more than 20 stamens, each with an anther more than 4 mm (0.16

Fig. 25. A flower of *Kurtziflora antherosa*, McIver *et al.*, 1991. This is the first flower discovered bearing the triprojectate pollen, *Kurtzipites trispissatus* Anderson. Scale bar = 6.0 mm. (Photo from McIver *et al.*, 1991).

inch) long, containing pollen sacs full of the pollen taxon *Kurtzipites trispissatus* **(Fig. 26).**

McIver *et al.* (1991) stated that the reduced ornamentation of the pollen *K. trispissatus* is consistent with anemophily (transport of pollen by wind rather than by insects).

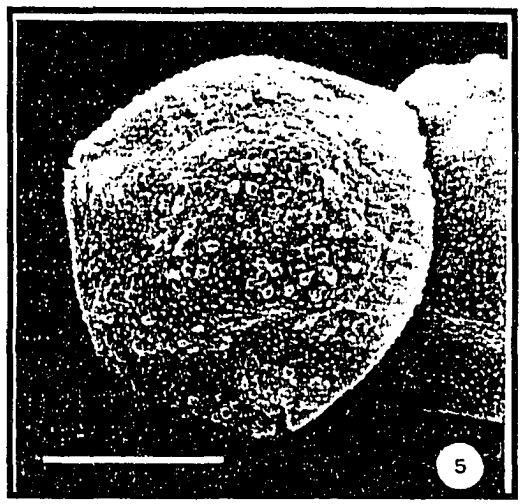

Fig. 26. *Kurtzipites trispissatus* Anderson. The pollen *K. trispissatus* exhibits scabrate ornamentation. Scale bar is 10 µm (Photo from McIver *et al.*, 1991).

McIver *et al.* (1991) further stated that there is some evidence for a small perianth on *K. antherosa*. This is important because Whitehead (1969) recognized that anemophilous taxa with a reduced perianth are deciduous. McIver *et al.* (1991) also stated

> the Ravenscrag Butte Flora, to which the plants bearing the fossil flowers belong, is interpreted as a deciduous, broadleaf and needleleaf flora.

McIver (1989) clarified that "all but one of the broadleaf types known from this flora are interpreted as deciduous." Thus the discovery of the fossil flower of the plant *K.*

antherosa is important for two reasons. First, *K. antherosa* is described as a

> small herbaceous form with decidedly deciduous characteristics useful for survival in a stressful environment

and is associated with a deciduous flora (McIver *et al.*, 1991). Second, the anthers of *K. antherosa* contain the pollen taxon *K. trispissatus* Anderson pollen, and this pollen genus is a known member of the *Aquilapollenites* Group. No other fossil plants or flowers associated with the *Aquilapollenites* Group pollen have ever been found. The deciduous character of *K. antherosa* was unknown prior to 1989 (McIver, 1989; McIver *et al.*, 1991). This information implies that assemblages with *Aquilapollenites* pollen contained at least some deciduous angiosperms. The very small size of the plant of *K. antherosa* adds support to Frederiksen's *et al.* (1987) conclusion in which they stated they had found 28 angiosperm pollen taxa they believed represent mostly herbaceous plants in the Campanian-Maastrichtian Arctic Alaska forest understory.

The Campanian-Maastrichtian paleomicrofloral assemblages from the Prince Creek Formation, Arctic Alaska,

contain abundant *Aquilapollenites* grains (Frederiksen, 1989, 1991; Frederiksen and Schindler, 1987; Frederiksen *et al.*, 1987) as well as *Kurtzipites trispissatus* Anderson, *K. anulatus* Norton, and *K. circularis* Norton (Frederiksen, 1991). Pollen assemblages from the Lower Cantwell Formation also contain many species of *Aquilapollenites* pollen (Sweet, 1994a, 1994b) and *K. andersonii* Srivastava (Sweet, 1994a; Ridgway *et al.*, 1997). This suggests that the Campanian-Maastrichtian paleoclimate of Arctic and Interior Alaska was seasonally arid and/or cool.

The 'triprojectate' morphology of *Aquilapollenites* form genera refers to the three lateral arms or projections emerging from the main axis of the pollen grains. Each of the six forms, *Aquilapollenites*, *Triprojectus*, *Hemicorpus*, *Mancicorpus*, *Integricorpus* and *Bratzevaea*, has this characteristic shape and profile. It must be noted that form genera of the *Aquilapollenites* Group, as illustrated by Takahasi and Shimono (1982) **(Fig. 27)**, did not include the *Kurtzipites* pollen form. However, McIver *et al.* (1991) emphasized that the structural characteristics of *K. trispissatus* which ally it to the *Aquilapollenites* Group are

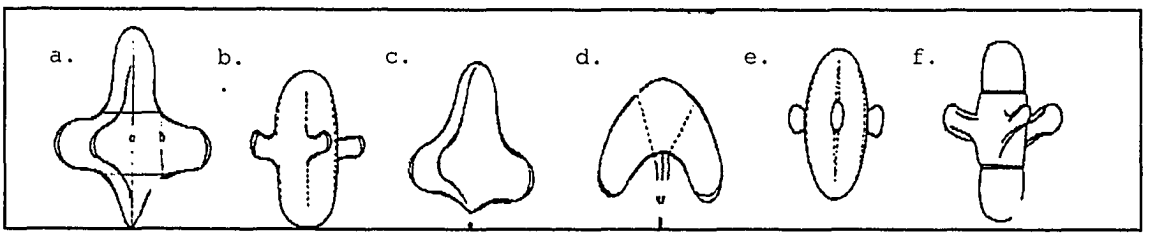

Fig 27. Aquilapollenites Group form genera: a. *Aquilapollenites*, b. *Triprojectus*, c. *Hemicorpus*, d. *Mancicorpus*, e. *Integricorpus*, f. *Bratzevaea* (modified from Takahasi and Shimono, 1982; Traverse, 1988).

> the presence of an endopore defined by endexinal costae... short colpi and a subtriangular outline in polar view... with slightly protruding apertural areas

emerging from the main axis of the pollen grains. Thus far, *K. trispissatus* is the only *Aquilapollenites* genus known to be produced by a deciduous plant (McIver *et al.*, 1991).

Characteristics of volcanic arc vegetation

Myers (1993, 1996) discussed Eocene fossil vegetation preserved in basins proximal to volcanic arcs. He reiterated that volcanic island arcs are intermediate composite stratovolcanoes along continental margins formed in response to subduction processes. Because

stratovolcanoes tend to build rapidly, they also erode rapidly, producing sediment ranging from gravel to silt, which collects in the basins. Such basins receive volcanic ash and plant materials as part of the sedimentary aggregate (Myers, 1996).

> Myers and Fisher (1994) stated that
>
> the paleobotanical record of many arc basins is often skewed toward vegetation growing during eruptive epochs... which may last as long as a few thousand years.

Myers (1993) also noted "...cyclical vegetational changes within short stratigraphic sequences." His example of a cycle begins with an abundance of fern fossils in juvenile volcanic detritus which are replaced by a low diversity vegetation of "weedy" trees and vines that is replaced in turn by a diverse forest. Repetitions of this cycle may represent "repeated events of volcanic devastation and recovery, and probably forced high rates of vegetational change" (Myers, 1996). This type of volcanic recovery cycle has been previously noted by others (Kruckeberg, 1987; Wolfe, 1987; Myers, 1993; Myers and Fisher, 1994).

Summary

The Matanuska Formation is part of the Talkeetna Volcanic Island Arc, which in turn is part of the Late Cretaceous north Pacific Rim. The literature documents paleofloras throughout this large expanse of continental margins that have limited numbers of *Aquilapollenites* Group species compared to inland paleofloras of northern Alaska, the Russian Far East and the Pacific Northwest of North America. This difference suggests that regional paleofloras and paleoclimates may be identified and differentiated.

The deciduous character of the recently discovered 65 million year old plant *Kurtziflora antherosa* which produced the pollen taxon *Kurtzipites trispissatus,* allied to *Aquilapollenites* form genera, is a useful interpretive tool. It is now possible to suggest that some of the plants which produced triprojectate *Aquilapollenites* pollen may be considered deciduous. The *Aquilapollenites* Province microflora ultimately suggests that regions where these plants were dominant must have had relatively arid or seasonally cold climates.

The literature also suggests that Late Cretaceous floras of the Nanushuk Group and the Colville Group of

Arctic Alaska were not subtropical, as initially reported but existed in a cooler and perhaps more seasonal environment. These new interpretations are based on ratios of angiosperms to gymnosperms (Frederiksen, 1989), the presence or absence of deciduous characteristics in plants (Spicer and Parrish, 1986; Wolfe and Upchurch, 1987; Parrish and Spicer, 1988; Spicer and Herman 1996), fossil leaf margin analyses (Wolfe, 1979; Spicer, 1987), dendrochronology (Spicer and Parrish, 1990), and pollen analyses indicating a decrease in the number of angiosperm species throughout the Campanian and Maastrichtian Frederiksen, 1989).

By the Late Cretaceous, east-west oriented land barriers existed in Alaska (Moore *et al.*, 1994). The ancestral Brooks Range divided the Arctic Alaska Terrane from interior Alaska, and the western and eastern sections of the Alaska Range separated interior Alaska from southcentral Alaska (Hudson, 1979; Barker *et al.*, 1994). These barriers may also be important factors in the development of distinct regional floras in Late Cretaceous Alaska (Samoilovich, 1966, 1977). Spicer (1987), noting that the Brooks Range may have served as a vegetation migration filter, suggested that it may also have

contributed to locally modifying the climate. He stated that

> the progressive loss of entire-margined magnoliid forms, ginkgophytes and cycadophytes [on the North Slope] throughout the Late Cretaceous suggests progressive climate deterioration.

Repeated volcanic eruptions in association with an island arc complicate vegetation reconstructions. Myers (1993) reported that pollen and spore data gathered from regions adjacent to island arcs reveal cyclic changes in vegetation. The Matanuska Formation contains significant deposits of volcanic tephra, thus the Matanuska paleomicroflora may demonstrate similar cyclic changes.

Ultimately, the literature hints that Campanian-Maastrichtian paleofloras along the Cretaceous continental margins of the North Pacific Rim, including Japan, represent one continuous coastal floral province analogous to, or perhaps homologous to, the North American Continental Margin Province recognized and named by Frederiksen (1987).

Finally, the literature shows that pollen sequences from the CWIS have been used to successfully correlate rock units and delineate the northern, central and southern

geographic regions of the CWIS (Nichols and Sweet, 1993). These taxa may thus be used to reconstruct the paleolatitude of the Matanuska Formation and constrain the time of accretion of the Wrangellia Composite Terrane.

III. Methods

Introduction

Exposures of the Matanuska Formation are located throughout the Talkeetna Mountains of southcentral Alaska. Mazuma Creek, the primary study site, is remote and only accessible by horse, helicopter, or plane. The first trip to Mazuma Creek **(Map in pocket)** was undertaken in 1992, by bush plane and helicopter, in order to inspect the area as a potential study site and to collect plant and invertebrate megafossils. During the second trip to Mazuma Creek in 1994, I examined the entire outcrop, collected rock samples, measured sections, and photographed all sample sites. In addition, my team and I walked to the headwaters of Mazuma Creek and around the perimeter of its drainage to visit several other small nonmarine outcrops of the Matanuska Formation that are indicated on Grantz's (1960) Geologic Map of the Talkeetna Mountains. These outcrops were primarily sandstone and conglomerate with no fine-grained rocks present; no samples were taken **(Figs. 14, 17, 28-47)**.

During the summers of 1993, 1995, 1996 and 1997, I collected rock samples from all other outcrops of the Matanuska Formation to which I was able to travel by foot, helicopter, bush plane, float plane, or automobile **(Map**

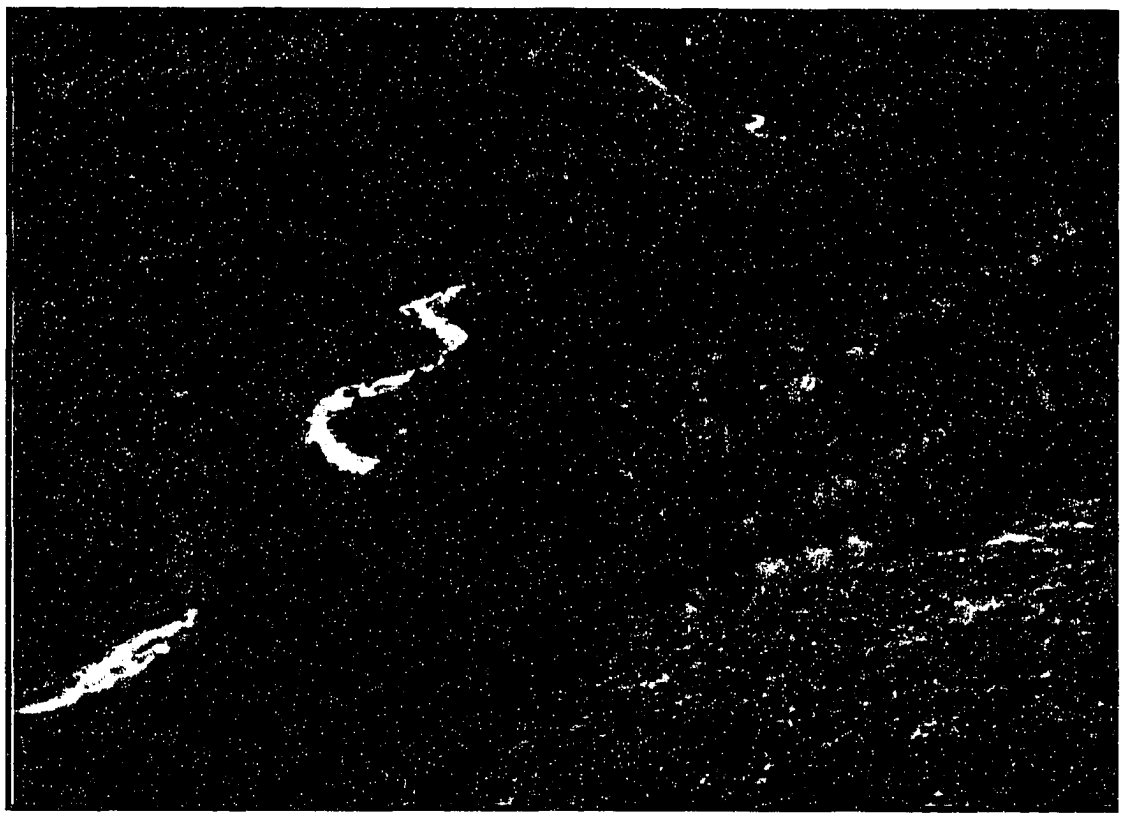

Fig. 28. West end of Mazuma Creek outcrop. (Photo by S. Reid).

in pocket, Table 17). These include outcrops at Granite Creek, Hicks Creek, Slide Mountain and Syncline Mountain. I also sampled rocks from several Campanian-Maastrichtian outcrops in Denali National Park and Preserve **(Table 17, Fig. 48-Site A)**. Finally, in 1995, I collected a small suite of fossil plants from an outcrop on the East Toklat River, one quarter mile downstream from where the Denali Park road abuts and parallels the East Toklat River **(Fig.**

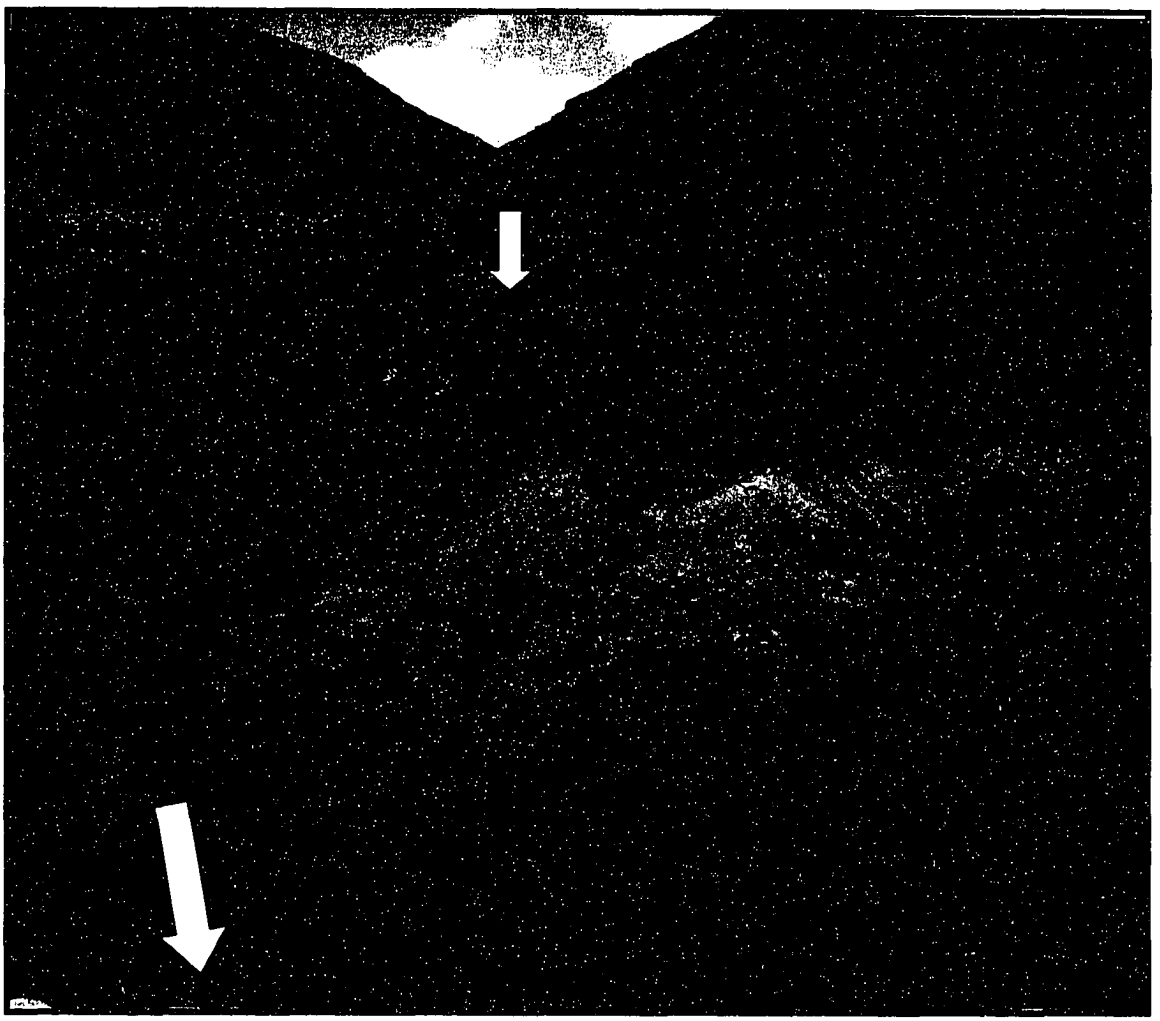

Fig. 29. Station 0 (large arrow) at the base of the Mazuma Creek outcrop. The survey of the vertical cross section begins at Station 0. The west end of the outcrop, showing conglomerate, sandstone, shale, and coal of the non-marine Matanuska Formation, is overlain by sediments deposited by marine transgression. Anne Pasch is at sample site A **(small arrow)**, and Lee Reid appears in the center of the photo (Photo by S. Reid).

48-Site B). The East Toklat River collection is stored at the University of Alaska Museum of the North.

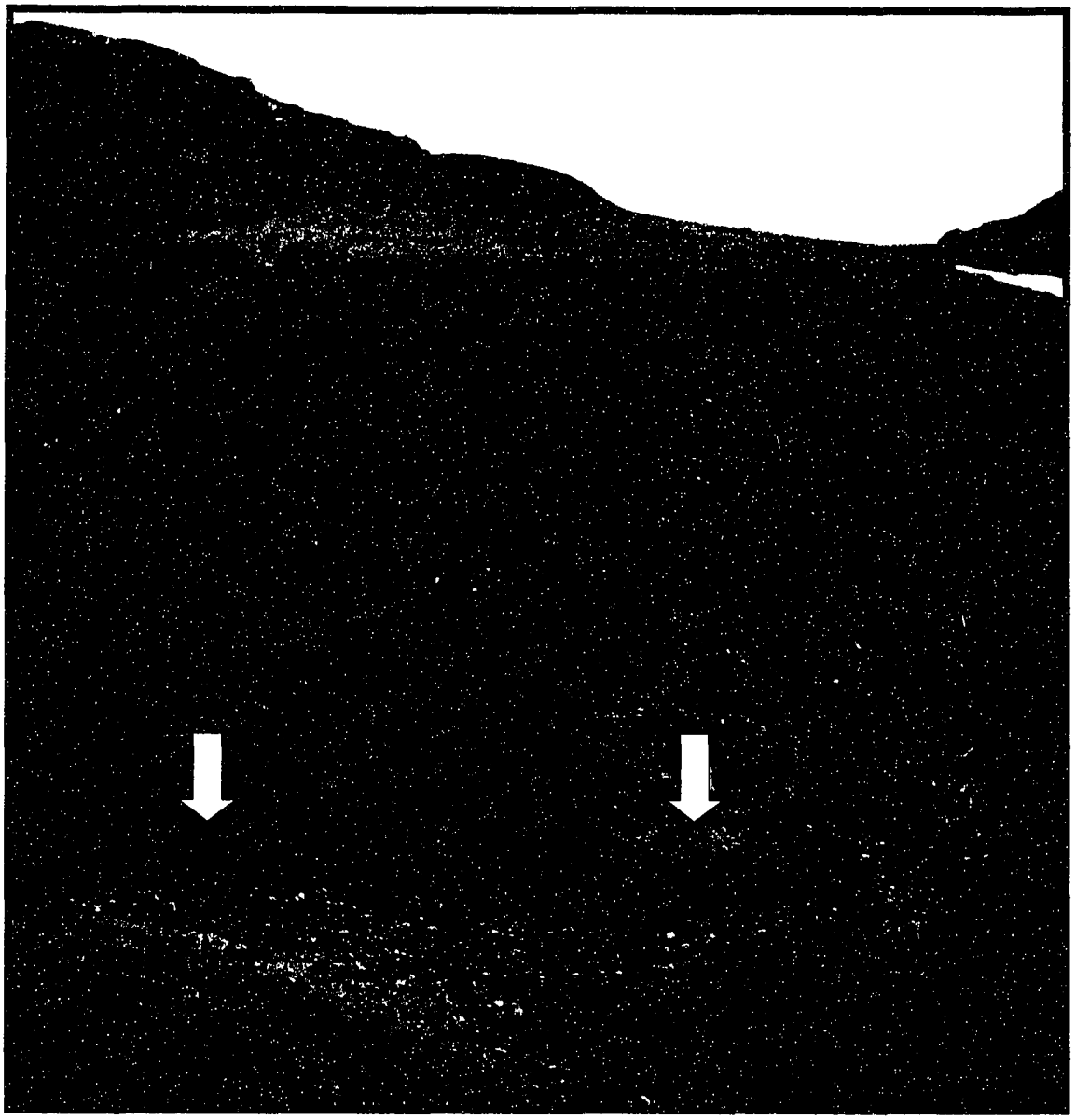

Fig. 30. East end of the Mazuma Creek outcrop. Opal Creek is the upper right fork of the stream, and Shower Falls Creek is the lower right fork in the center of the photograph. Stations 14 and 15 are visible along the base of the outcrop **(arrows).** Stations 16 and 17 are to the northeast of Station 15 up Opal Creek. Lee Reid is standing at Station 14 for scale (Photo by S. Reid).

Table 17

Sampling Schedule, 1992 to 1997

Date	Location of Sampling Sites	No. Of Samples Collected	Field Associates and Assistants
1992	Mazuma Creek **(Map in pocket)**	none	Lee Reid, Anne Pasch, Roland Gangloff, & Don Triplehorn
1993	Wolverine Creek, Kings River to Hicks Creek, Granite Creek in Upper Matanuska Valley **(Map in pocket)**	59	Lee Reid
	Moose Creek in Upper Matanuska Valley **(Map in pocket)**	1	Anne Pasch
1994	Mazuma Creek **(Map in pocket)**	40	Lee Reid, Anne Pasch
	Slide Mountain **(Map in pocket)**	6	Dennis Clark, Tony DeLucia
1995	Denali-Polychrome Mt, **(Fig. 48-A)**	22	Lee Reid, Sue Kurtz
	East Toklat River **(Fig. 48-B)**	18	
1996	Syncline Mountain **(Map in pocket)**	13	Lee Reid, Kevin May
1997	Hicks Creek **(Map in pocket)**	1	Lee Reid, Kevin May

Samples from Mazuma Creek sites A, B, C, E, and F **(Appendix A)** were processed by Global Geolabs of Medicine Hat, Alberta, Canada. This set contains 23 slides. Palynological processing of samples from sites D (Mazuma Creek), G (Syncline Mountain), H (Hicks Creek), I (Slide Mountain), and J (Granite Creek) **(Appendix A)** for palynomorphs was performed in ARCO labs. There are 28 slides in this set. I borrowed slides of pollen and spores from samples of the Lower Cantwell Formation processed in 1994 by Dr. Arthur Sweet of the Canadian Geological Survey, rather than process the samples I had collected in that region. There were 200 slides in his collection.

I examined all of the slides with a Zeiss microscope. I measured, sketched, counted and photographed selected palynomorph specimens from my collection sites, compiled the information in several large notebooks, and arranged photographs of selected specimens on 193 photographic plates **(Appendices A-J)**. I did not incorporate into this report any photographs of Dr. Sweet's palynomorphs from the Lower Cantwell Formation, but I did review and quote portions of his unpublished data.

Lithostratigraphic sections of the Mazuma Creek outcrop

The outcrop along Mazuma Creek **(Figs. 14, 28-47)** reveals a classic marine transgressive sequence over nonmarine sandstone, conglomerate, shale and coal. However, the section is only partially visible due to erosional deposits that cover most of the outcrop between sample sites E and F **(Fig. 31).**

During the 1994 field season, I compiled a composite vertical section of the Mazuma Creek outcrop. Field Assistants Lee Reid and Anne Pasch surveyed the canyon floor using a hand level and rod to determine elevations. They established 18 points of reference (Points 0 through 17), at 100 foot intervals. The change in elevation from Point O at the southwestern end of the outcrop at Point 17 to the northeastern end is approximately 53 m (175 ft). Points 15, 16 and 17 were reached by turning northeast at the confluence of the small tributaries Opal Creek and Shower Falls Creek and heading up Opal Creek for approximately 76 m (250 feet) **(Figs. 28-32).**

Using the 18 survey points on the canyon floor as a baseline, I selected, measured, and drafted six sections (A, B, C, D, E-1 and E-2) along Mazuma Creek **(Figs. 34, 37, 38, 40, 42, 43.** I also collected and identified rock

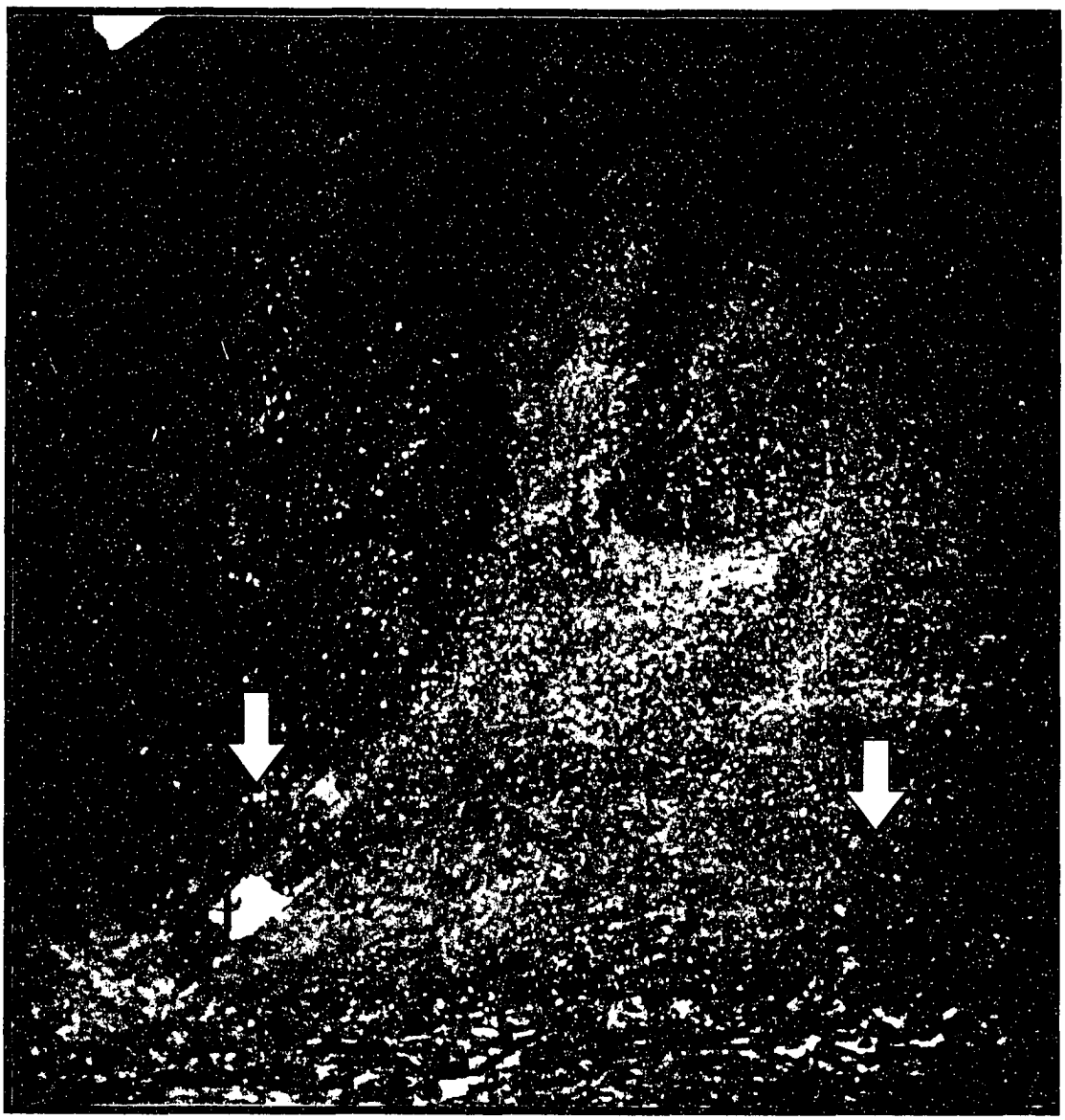

Fig. 31. Mazuma Creek outcrop at survey Points 9 and 10 (arrows). Between sample sites E and F of the Mazuma Creek outcrop many areas, such as the location between survey Points 9 and 10, are covered with erosional deposits. Lee Reid is conducting the survey of outcrop at Point 9 with assistant Anne Pasch at Point 10 (Photo by S. Reid).

samples from discreet units of carbonaceous sandstone, coal, and claystone, as noted on the measured sections **(Figs. 34,**

37, 38, 40, 42, 43). Sections A and B are between Points 0 and 1, Section C is between Points 1 and 2, Section D is between Points 3 and 4, and Sections E-1 and E-2 are between Points 5 and 6. Section F is between Points 16 and 17. The canyon wall between Points 6 and 16 is covered with alluvium or vegetation and was not sampled **(Fig. 32).**

Each section of outcrop was measured with a Jacob Staff, marked in feet and tenths of feet, and the data were recorded in a field notebook. The following samples, noted in the vertical sections, were collected:

5 samples from Section A,

6 samples from Section B,

6 samples from Section C,

15 samples from Section D,

1 sample from Section E-1,

5 samples from Section E-2,

2 samples from Section F.

A total of 40 rock samples were collected from six sections **(Table 17).** By tracing coal seams from Section A through Section E-2, I was able to determine the sequence of depositional events and reconstruct a complete vertical section of the outcrop (**Figs. 34, 37, 38, 40, 42, 43).**

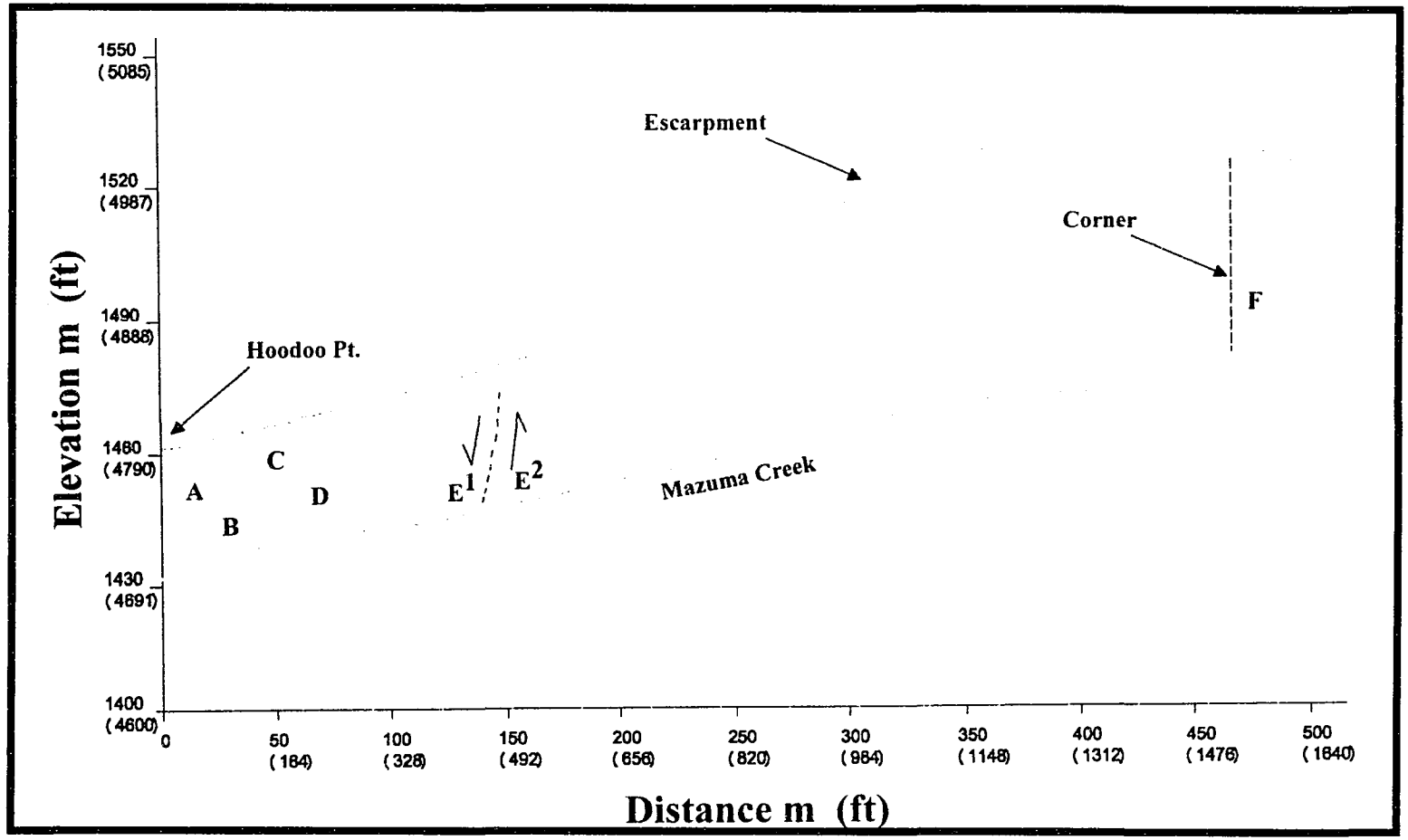

Fig. 32. Vertical cross section of Mazuma Creek outcrop: Sample sites and measured section are at Sites A-F. Survey points 0-17 are marked along the length of the Mazuma Creek Bed. Length 518 m (1,700 ft); rise, 35 m (175 ft).

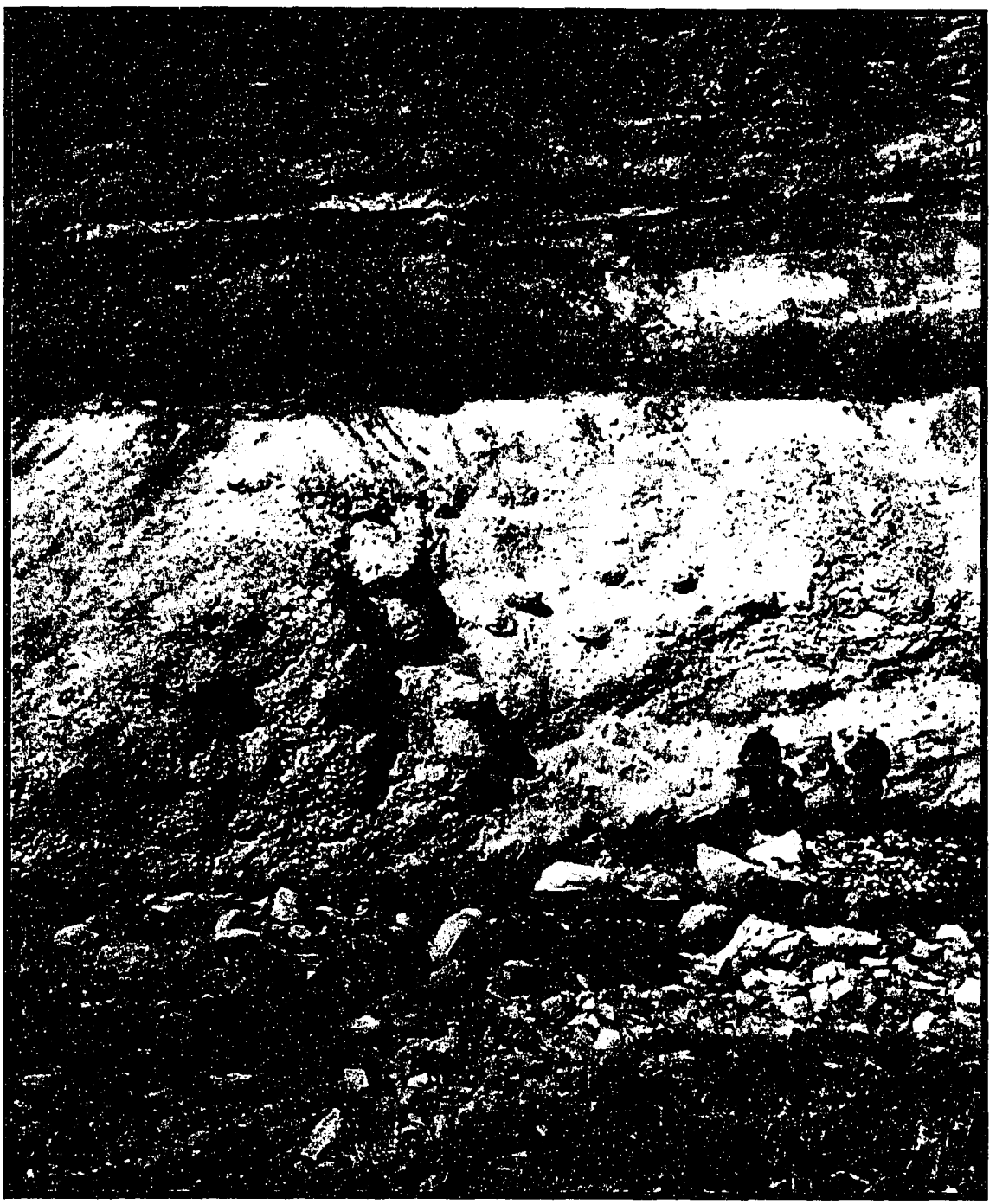

Fig. 33. Site of Section A. This photograph illustrates the lithology of Section A. Cross-bedded conglomerates are visible blow the coal seams (Photo by S. Reid).

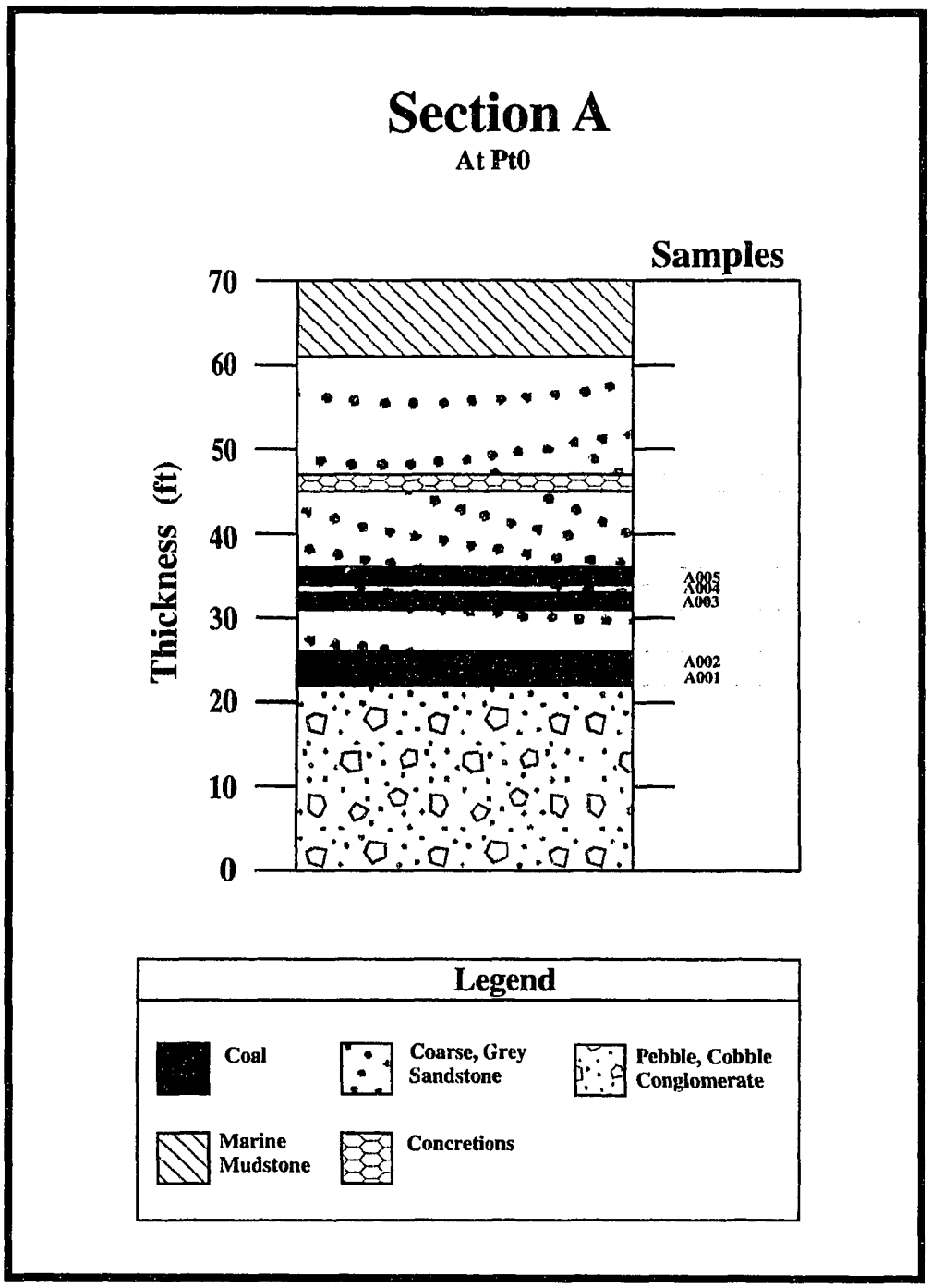

Fig. 34. Lithostratigraphic Section A, Mazuma Creek.

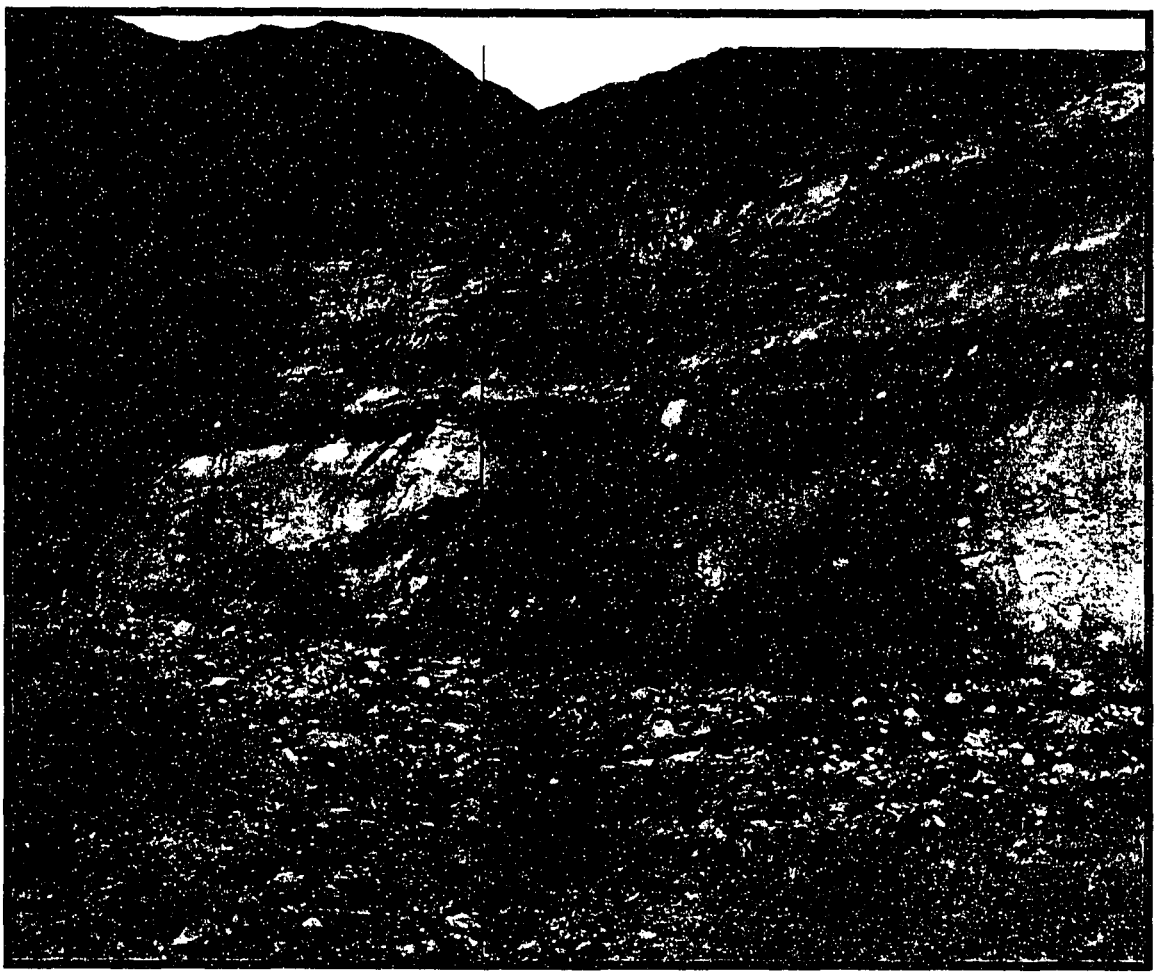

Fig. 35. Site of Section B. This composite photograph illustrates the lithostratigraphic section at site B (Photo by S. Reid).

Palynological sampling techniques

Ten sites in the Talkeetna Mountains with outcrops of the Matanuska Formation were visited and sampled for palynomorphs **(Map in pocket, Table 17)**. All sample collection points at each site were noted on my field maps.

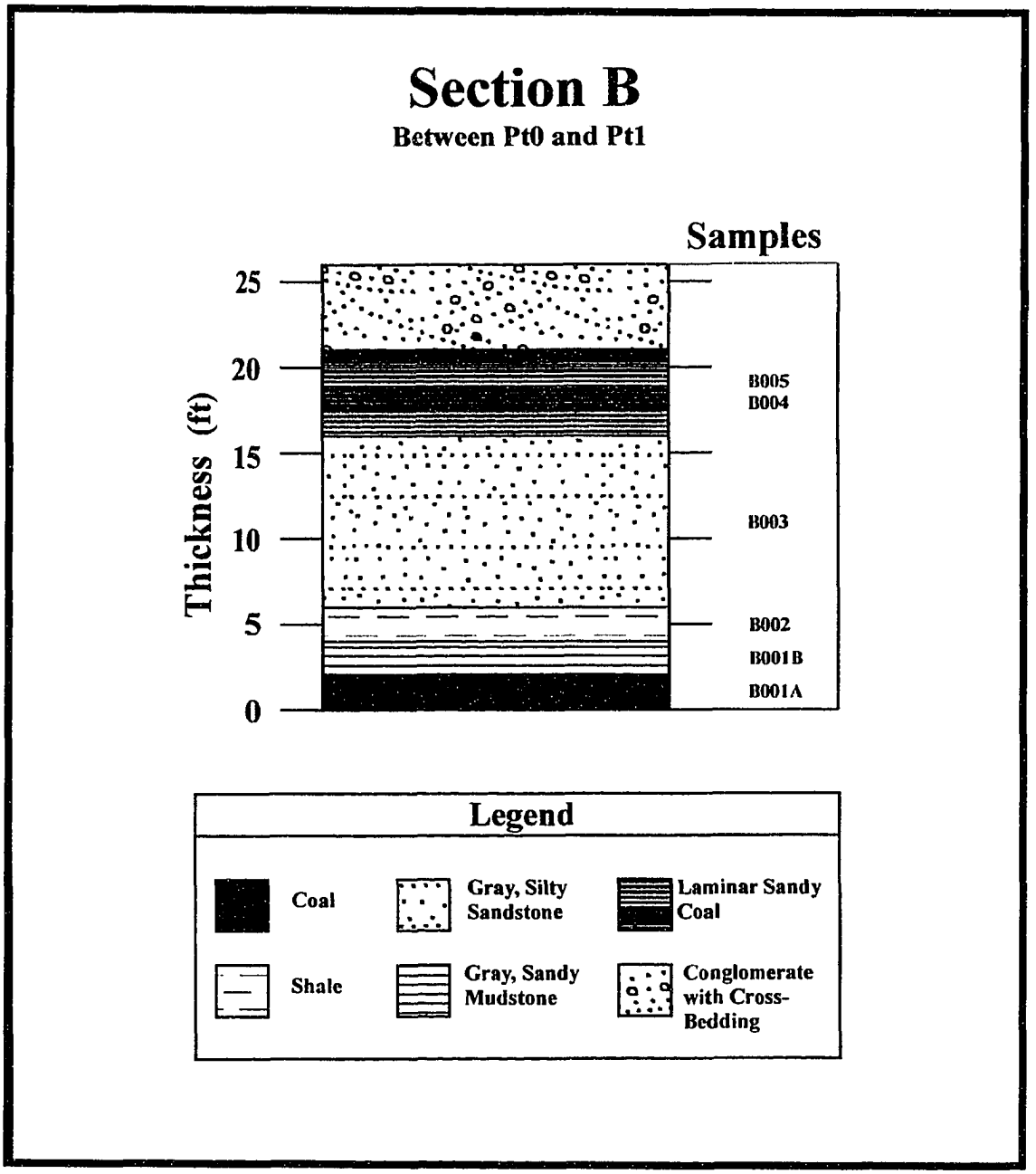

Fig. 36. Lithostratigraphic Section B, Mazuma Creek.

Fig. 37. Site of Section C. This photograph illustrates the lithostratigraphic section at site C (Photo by S. Reid).

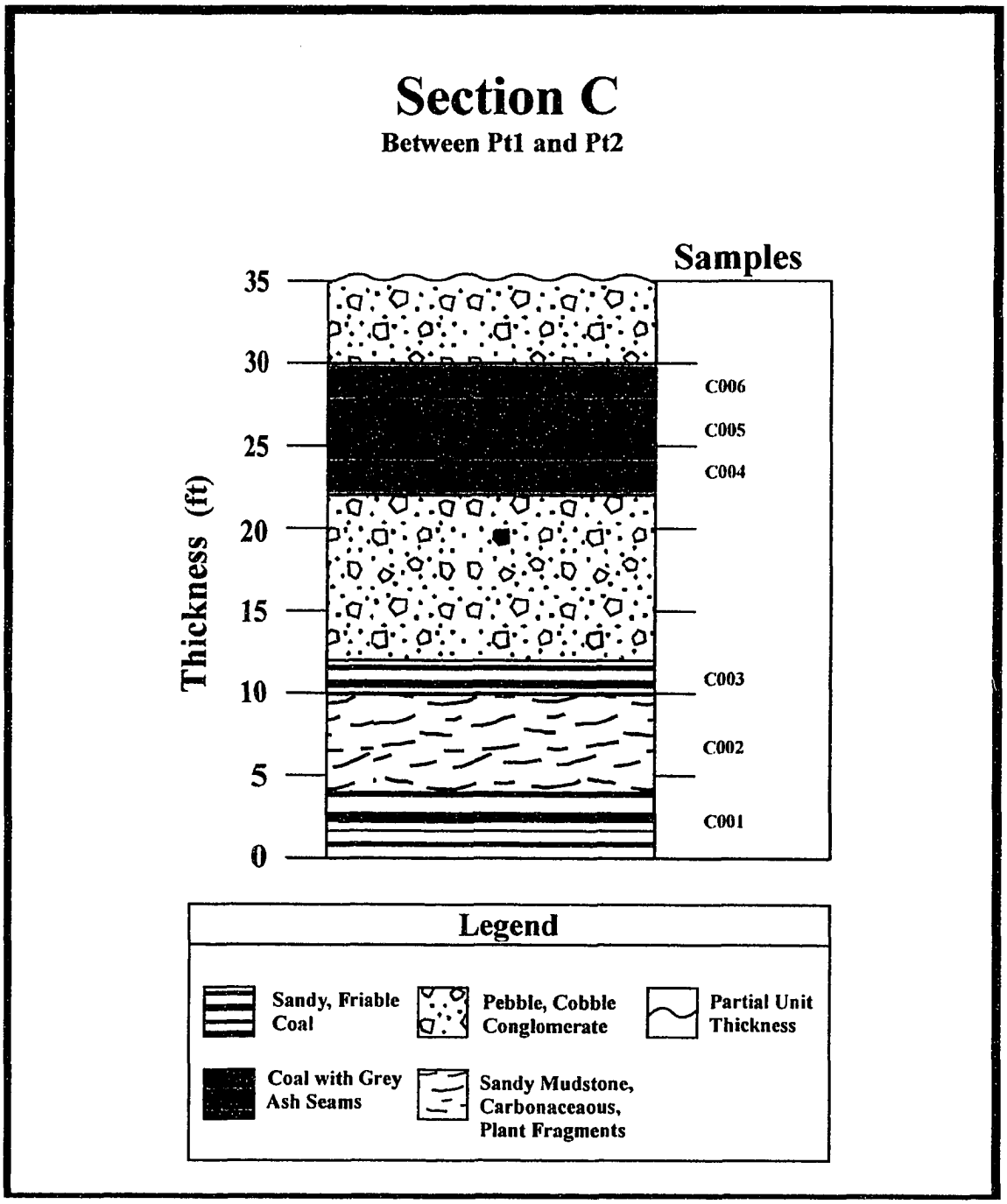

Fig. 38. Lithostratigraphic Section C, Mazuma Creek.

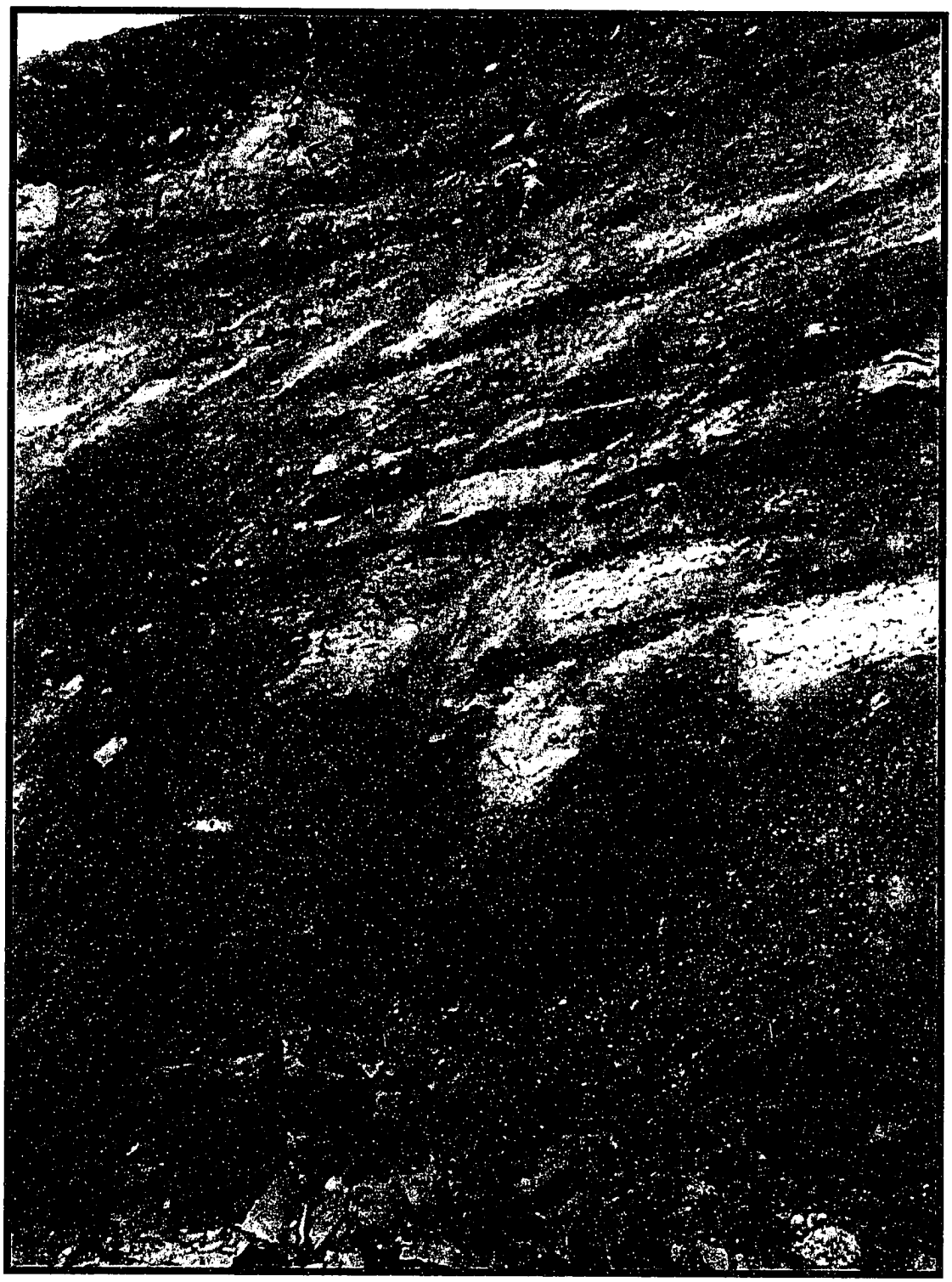

Fig. 39. Site of Section D. This is a photograph of the lithostratigraphic section at site D (Photo by S. Reid).

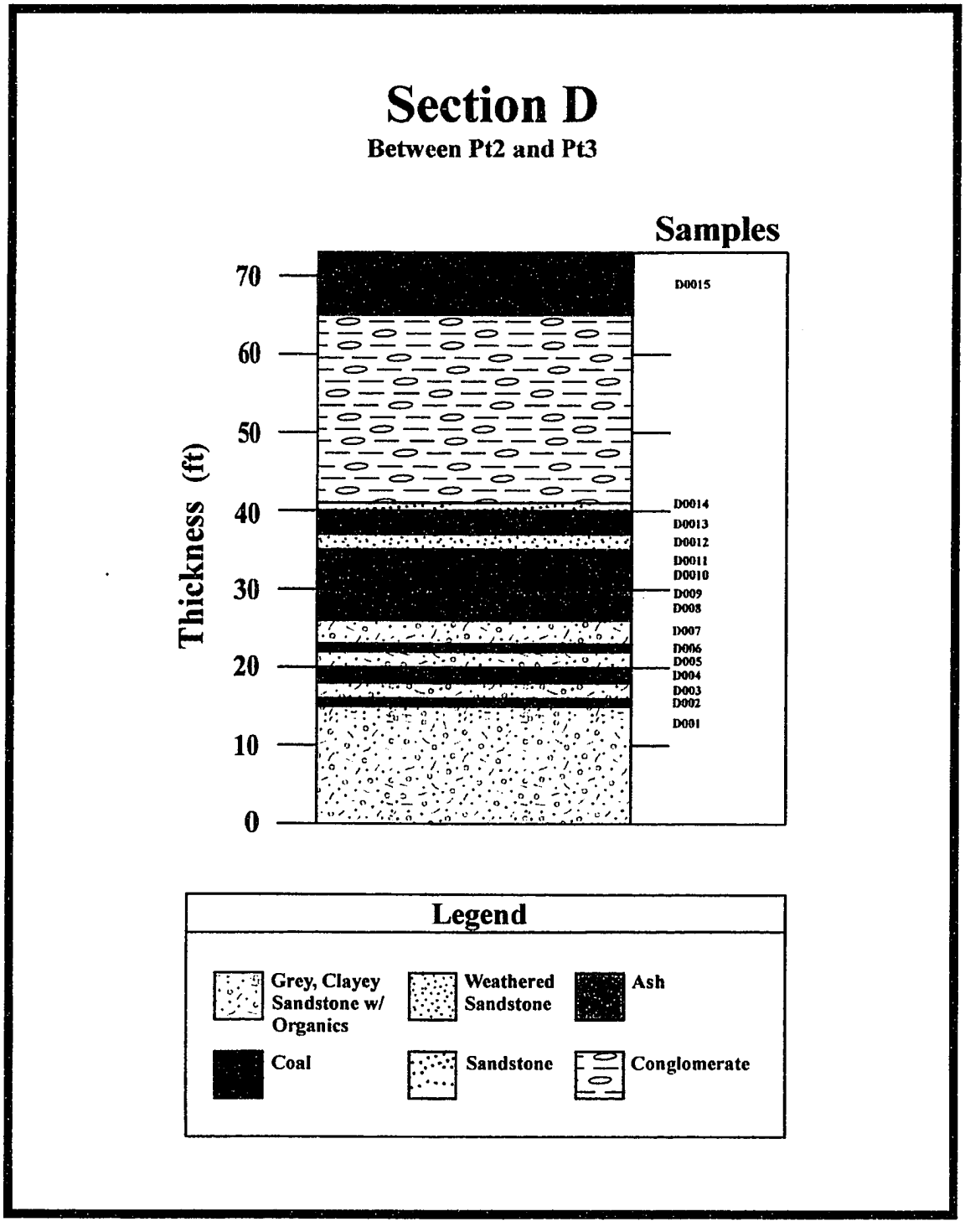

Fig. 40. Lithostratigraphic Section D, Mazuma Creek.

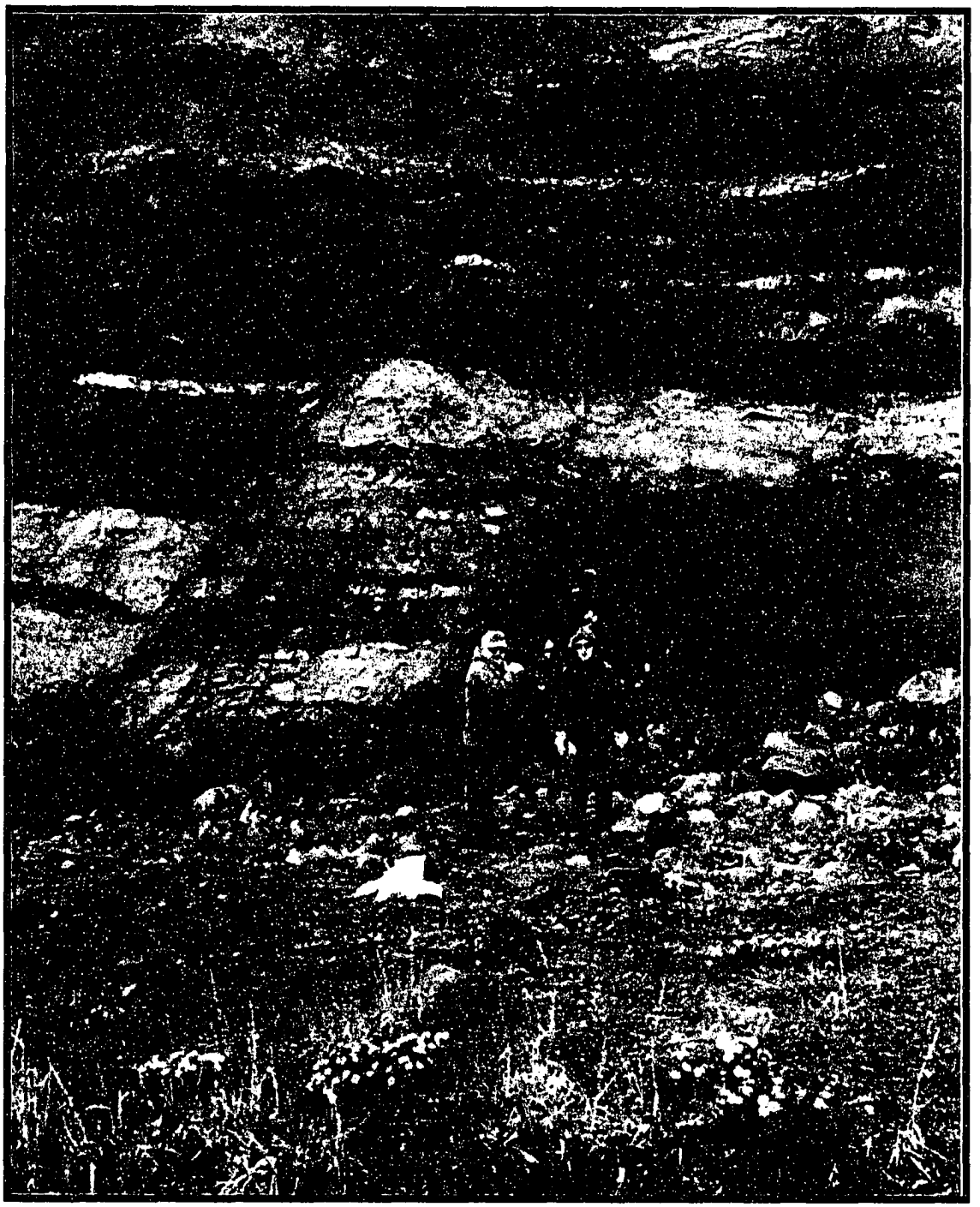

Fig. 41. Site of Sections E-1 and E-2. This is a photograph of the lithostratigraphic sections at site E-1, which is to the left of the normal fault, and site E-2 which is to the right of the normal fault (Photo by S. Reid).

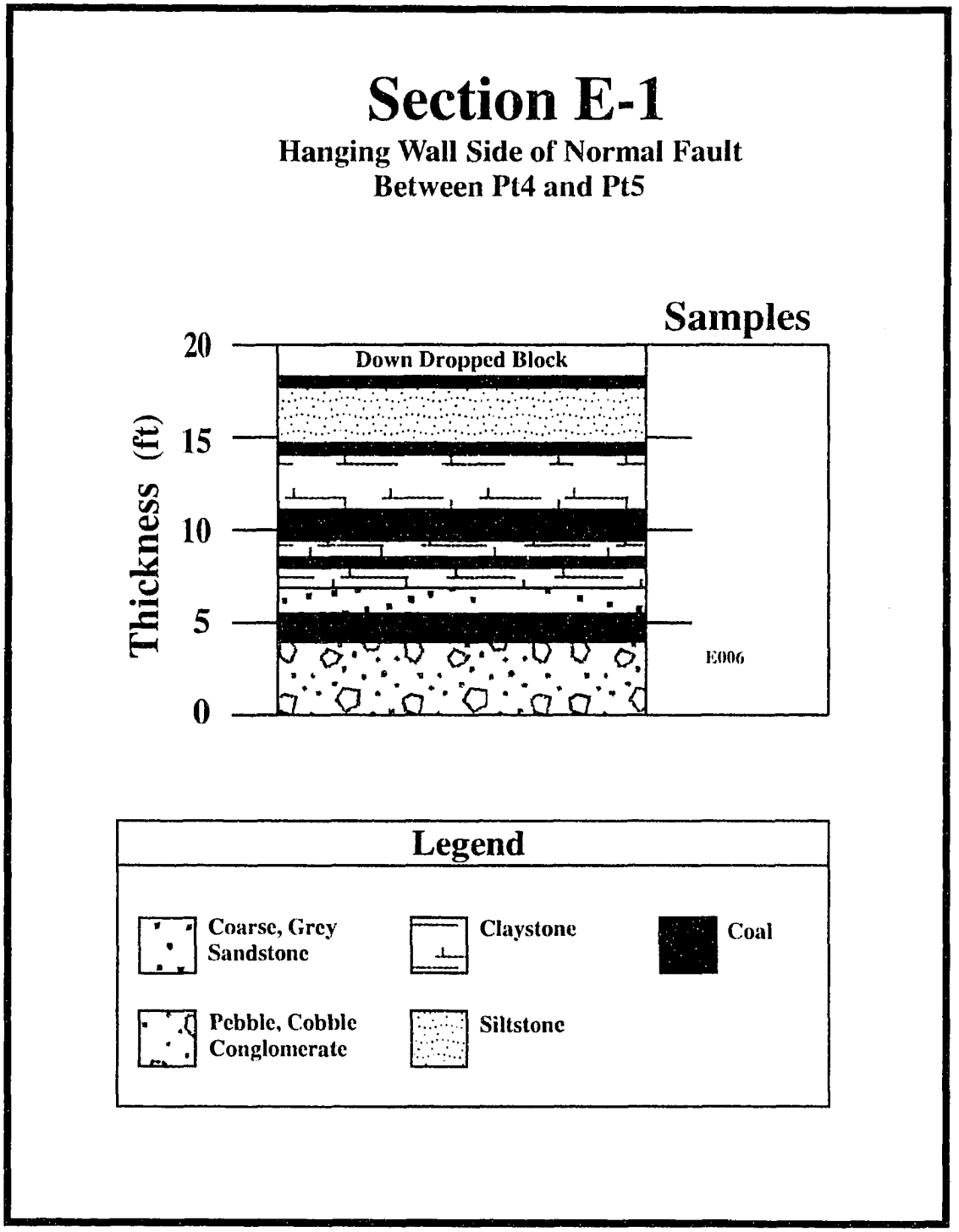

Fig. 42. Lithostratigraphic Section E-1. The hanging wall side is on the left side of the normal fault, Mazuma Creek.

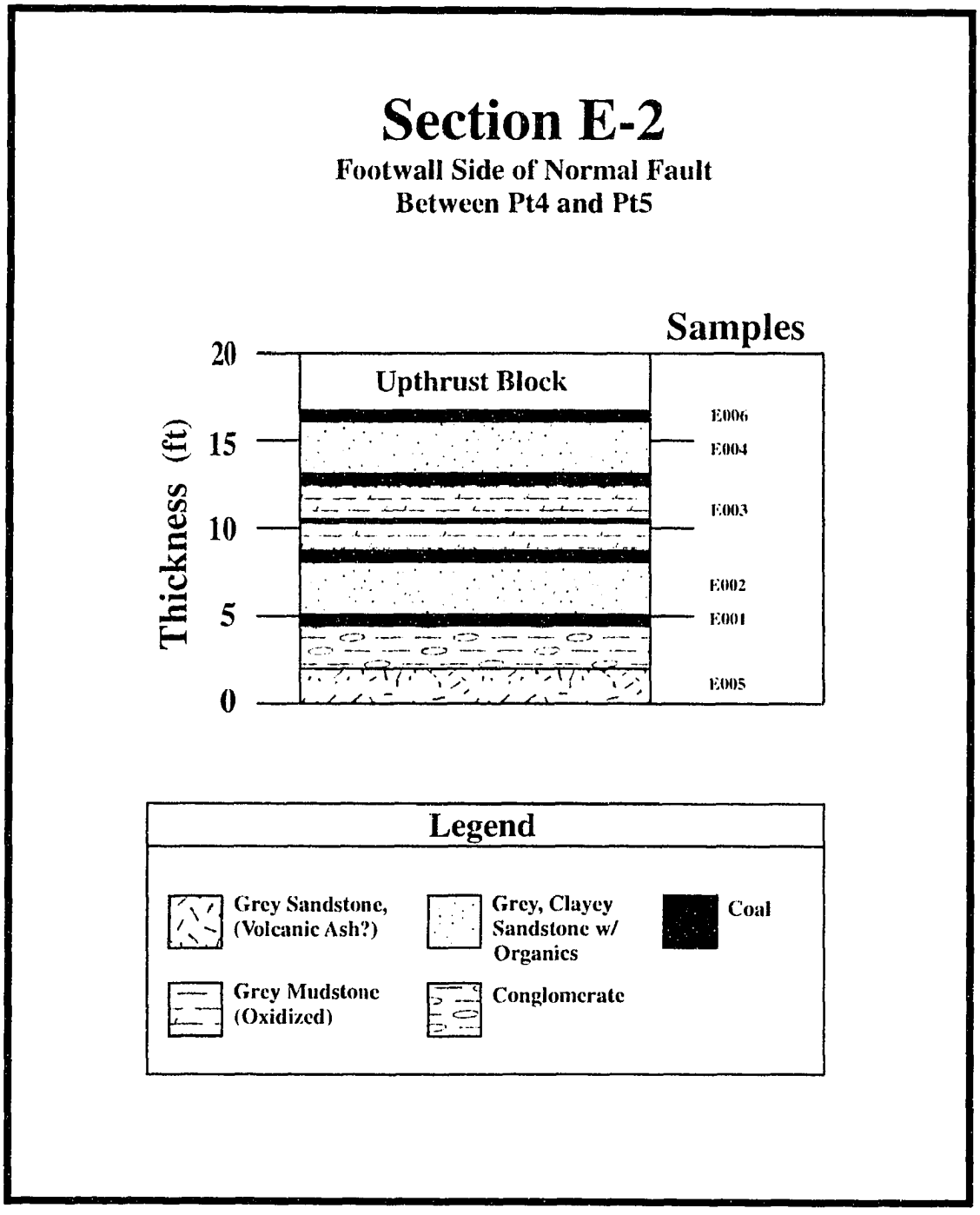

Fig. 43. Lithostratigraphic Section E-2. The footwall side of the section is on the right side of the normal fault, Mazuma Creek.

To take a pollen sample from an outcrop, I used a rock hammer or a small spade to trench in and upward to find material that was fresh and unweathered. I collected about 454 ml (1 measure cup) in volume per sample, and stored each sample in a numbered and labeled Zip-Loc bag. These data were also recorded in my field notebooks. During the summer of 1993, I collected 59 rock samples. Forty-six samples were collected from road cuts along the old Glenn Highway between the village of Sutton and Hicks Creek **(Map in pocket)**. Road construction realigned the Glenn Highway during 2000-2003, and most of the outcrops have been destroyed. Six additional samples were obtained from outcrops along Granite Creek and one sample was taken along Moose Creek. The Moose Creek sample was taken from an outcrop about one half mile down river from the Moose Creek Campground which is situated approximately ten miles north of Palmer on the Glenn Highway. Six pollen samples were also collected east of the Matanuska River along the south bank of Wolverine Creek **(Map in pocket, Table 17)**.

In early August, 1994, I flew into Carrot Lake near the eastern summit of Slide Mountain **(Map in pocket)** with two field assistants, Dennis Clark and Tony DeLucia. Slide Mountain is approximately 20 miles north of the Talkeetna

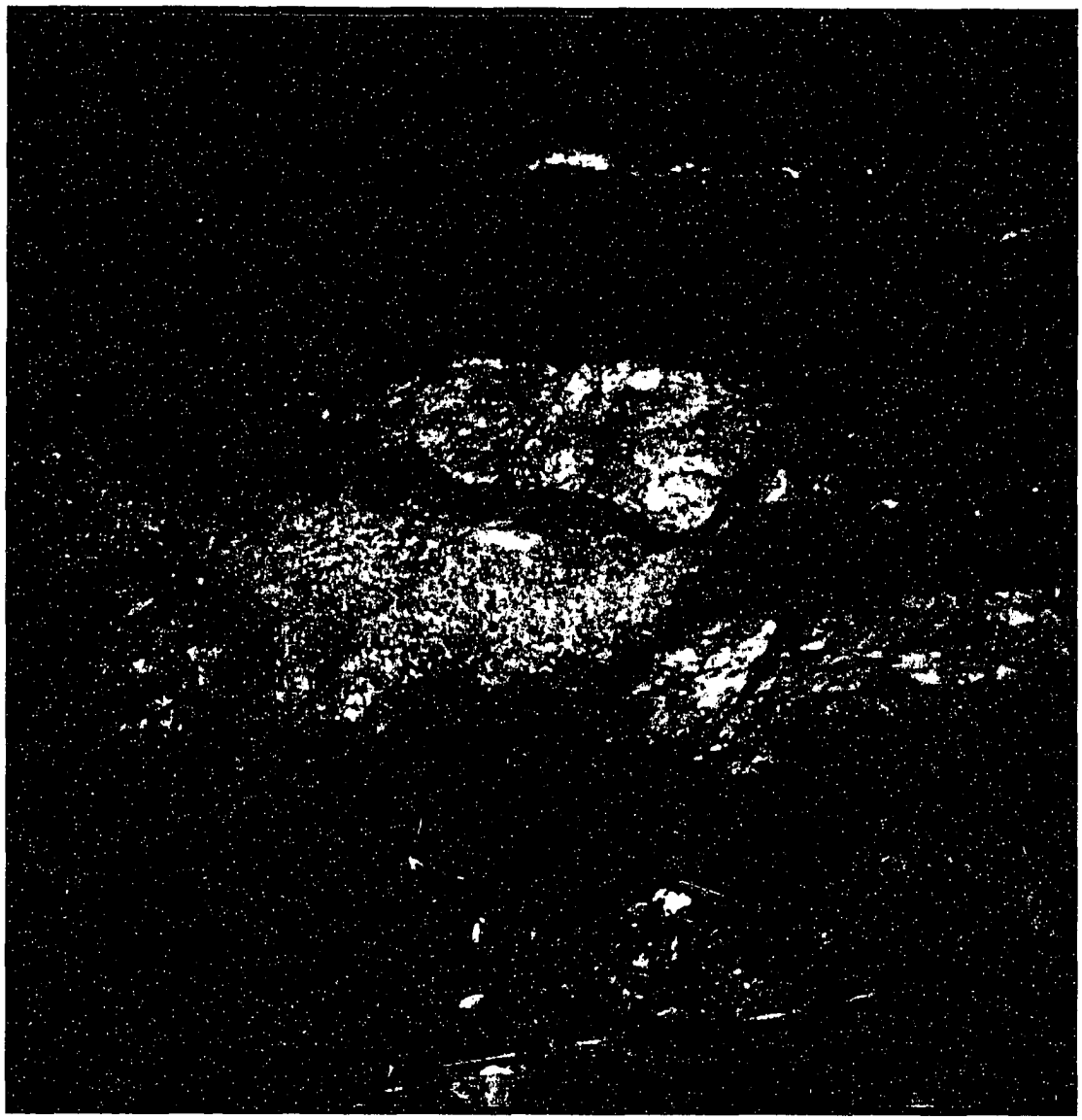

Fig 44. Close-up of normal fault between Points 4 and 5 (Figs. 42, 43). Section E-1 is to the left of the fault, and section E-2 is to the right of the fault. The left arrow points to the location of sample site E-006 while the right arrow points to sample site E-005. Anne Pasch is for scale (Photo by S. Reid).

Mountains, at Mile 141, Glenn Highway. I conducted three traverses along the ridge top, and collected six pollen

Fig. 45. Site of section E-2. Locations of Samples E-001, E-002, E-003, and E-004, taken from the bottom to the top of the outcrop, are marked in pink. The measuring rod and rock hammer are for scale (Photo by S. Reid).

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samples from the marine deposits in which fossil brachiopods and scraps of fossil ammonites were common as float.

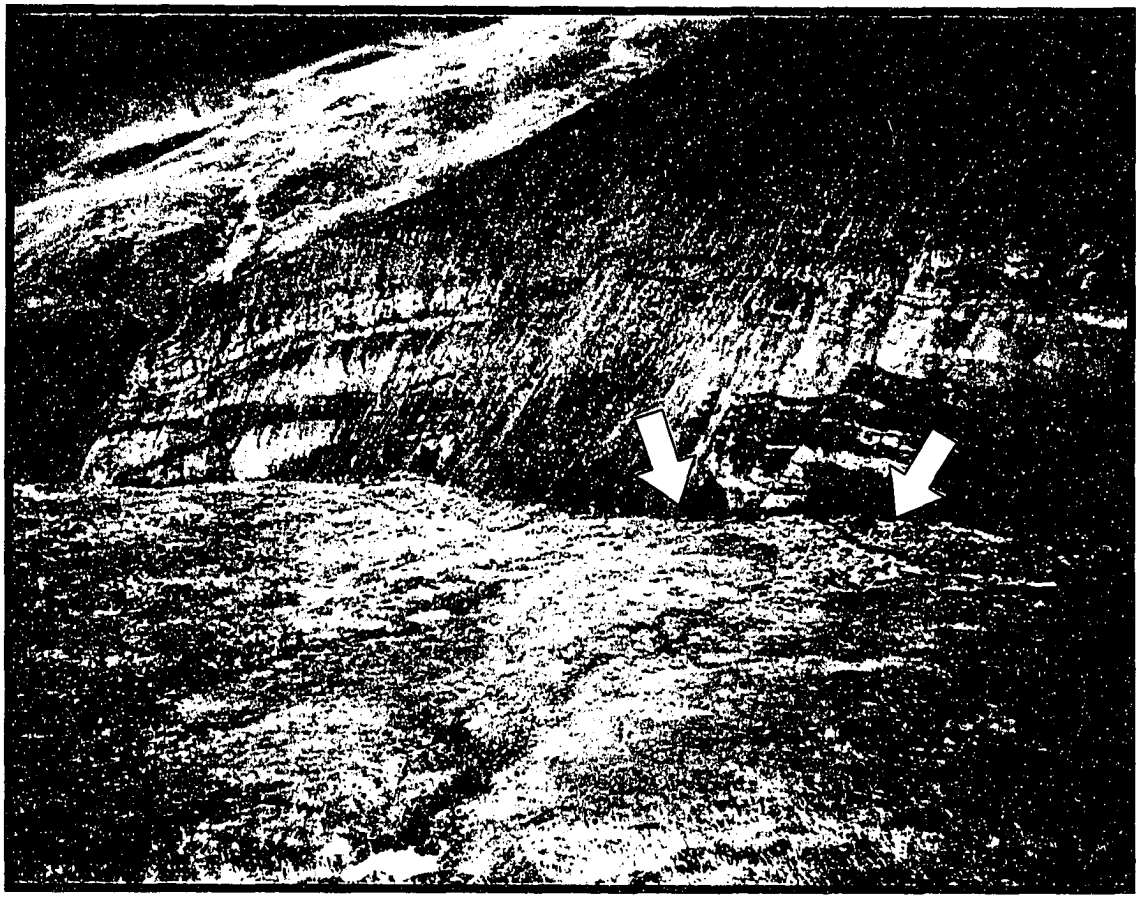

Fig. 46. Coal seam outcrop. The coal seam is slightly offset by a normal fault (Stratigraphic sections E-1 and E-2) **(arrows).** Hoodoo Point, and survey Point O are located at the extreme left of the photograph, to the southwest. The left arrow shows survey Point 4 **(Fig. 32)** to the left of the fault, and the right arrow shows survey Point 5 **(Fig. 32)** to the right of the fault. Erosional deposits cover some coal seams (Photo by S. Reid).

In 1995, I received permits from the Denali National Park Service to collect Campanian-Maastrichtian megaflora from the Lower Cantwell Formation along the East Toklat River and pollen samples from sites at Polychrome Peak **(Fig.**

48). The fossil plant materials were placed in the collections at the University of Alaska Museum of the North. My rock samples were not processed because slides of material from Polychrome Peak sections were made available to me by Dr. Arthur Sweet of the Canadian Geological Survey.

In 1996, Dr. Lee Reid and I hiked to the top of Syncline Mountain **(Map in pocket)** and collected 13 rock samples between approximately 4,000 and 5,000 ft. elevation. In 1997 Dr. Reid, Kevin May and I traveled by four-wheeler to Pinochle Pass and down into Hicks Creek drainage near the headwaters **(Figs. 49, 50) (Map in pocket)**. I collected one rock sample at the first outcrop with bedding on the east side of the river as we were hiking down the streambed. The sample was taken at approximately 30 m (100 feet) above the streambed and the alluvium.

Preparation of palynomorphs

Twenty-eight samples were professionally processed by Carl Sterrett, a laboratory technician for ARCO Alaska. The initial preparation included cleaning, rinsing, and crushing. Approximately 14 ml (1 tablespoon) of each prepared sample was placed in a glass vial and treated with hydrochloric acid (10% by volume, lab grade) to remove carbonates. Next the silicates were removed from the

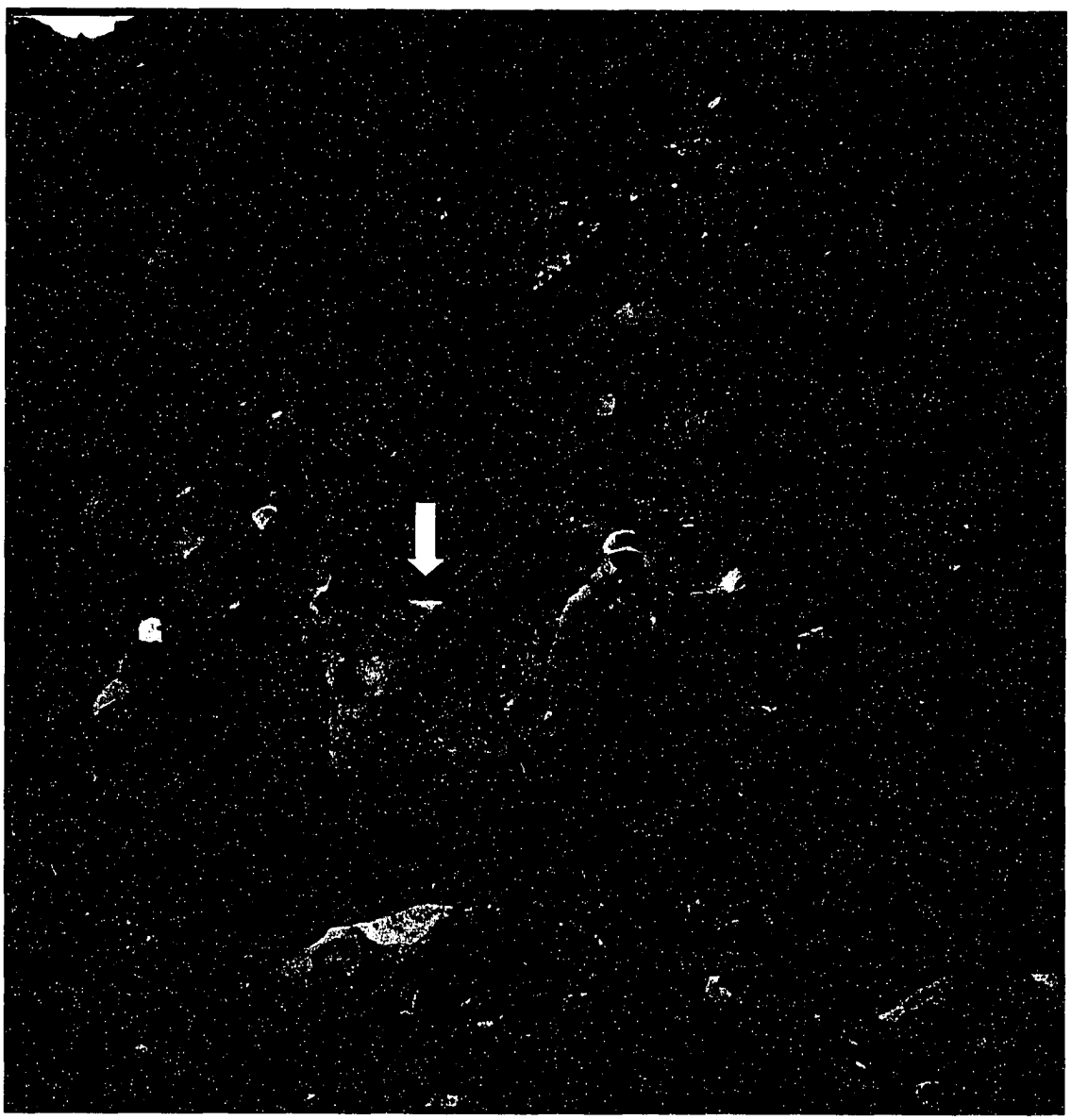

Fig 47. Close up view of conformable contact between non-marine (lower bed, tan) and marine (upper bed, gray) Matanuska Formation rocks (arrow) at Sample Site F on Opal Creek. Anne Pasch is standing at sample site F001 and Lee Reid is standing next to sample sites F002 and F003. Specimens of the scaphopod mollusc *Dentalium* and *Rhynchonellid* brachiopods were found at the marine-nonmarine interface (arrow) (Photo by S. Reid).

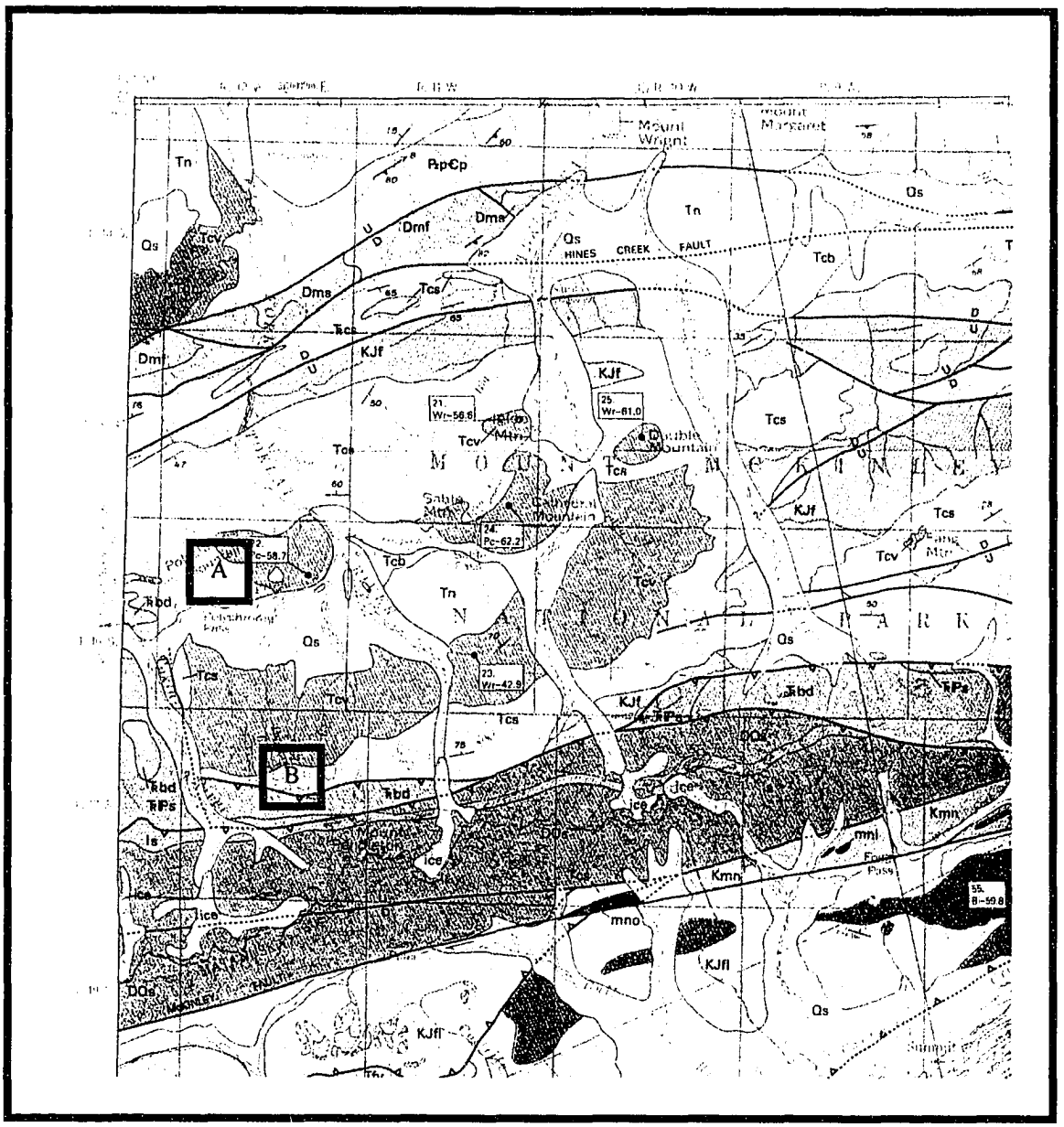

Fig. 48. Geologic map of sample sites A and B in Denali National Park and Preserve. Twenty two sediment samples were collected from the section at sample site A **(Table 17)** and 19 samples, as well as a small fossil plant collection, were taken at sample site B **(Table 17)**. The Lower Cantwell Formation, **Tcs**, noted as Tertiary sediments by Csejtey *et al.*, (1992), was redated by Sweet (*in* Ridgway *et al.*, 1997) as Campanian-Maastrichtian in age (Map modified from Csejtey *et al.*, 1992).

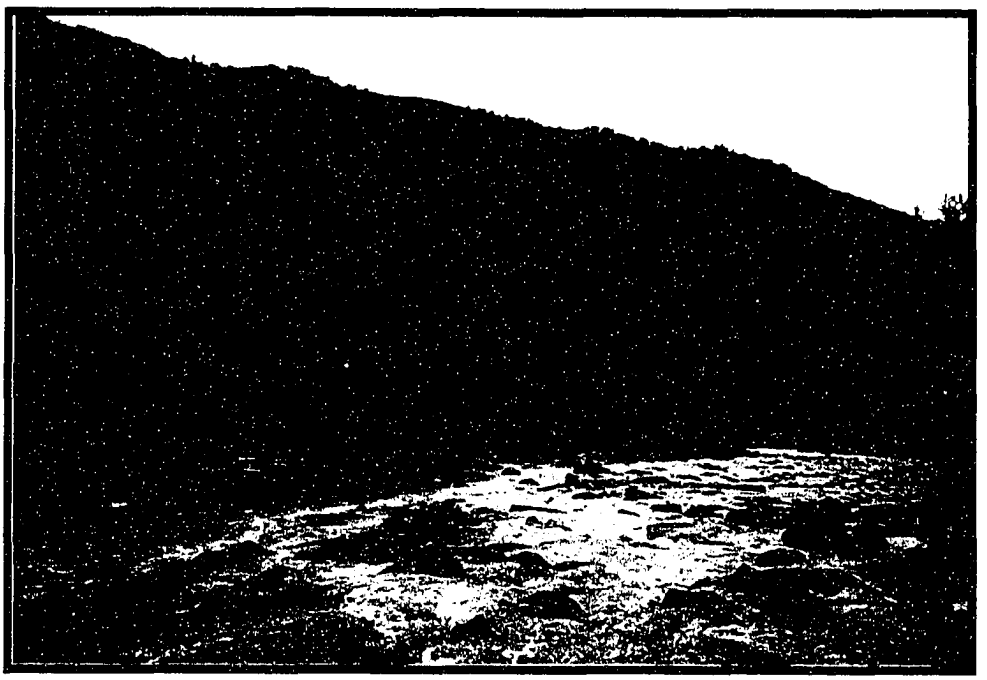

Fig. 49. Outcrop near headwaters of Hicks Creek (Photo by S. Reid).

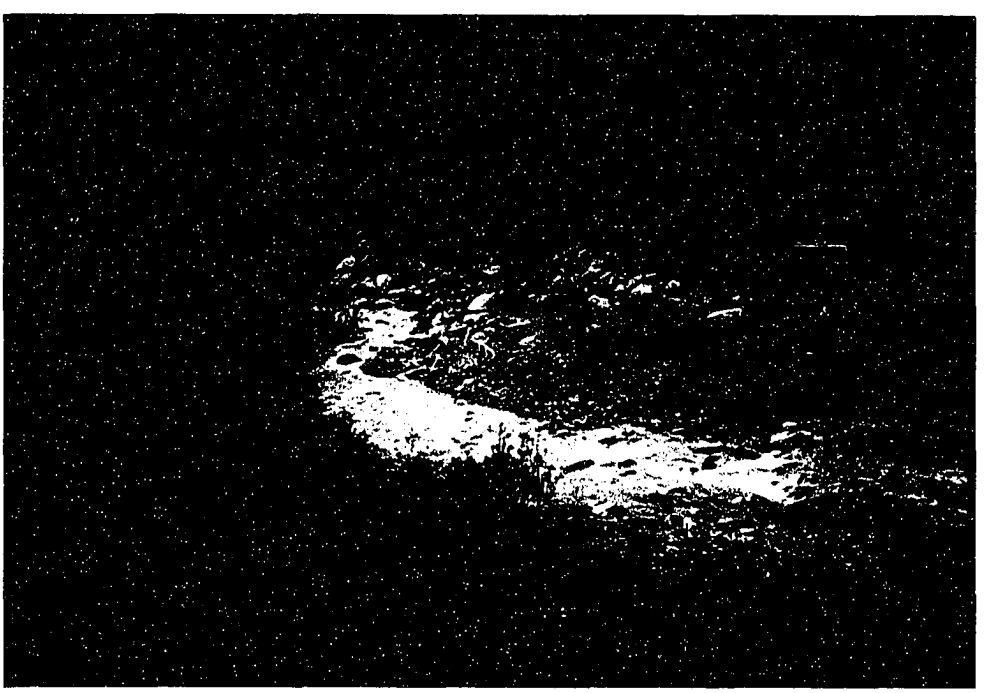

Fig. 50. View from near the top of the Hicks Creek outcrop. Kevin May is standing on the east bank of Hicks Creek (Photo by S. Reid).

samples using hydrofluoric acid (70% by volume, lab grade), followed by treatment of all samples with concentrated nitric acid (64%) to oxidize excess organic material. Oxidized plant material was then removed by dissolving it with a solution of potassium carbonate (10% by volume, lab grade). The remaining organic matter was separated by centrifuging it in a zinc bromide solution with a specific gravity of 1.9, which causes it to float. The organic residue was divided into two different size fractions, 10-20 microns, and 20-150 microns, and the residues were mounted on glass slides in Elvacite thinned with a small amount of xylene.

The second set of 23 samples was processed by Russell Harms, Global Geolabs, Medicine Hat, Alberta, Canada, using the same techniques, except that the organic residue was not divided into two different size fractions before being mounted on glass slides.

Loan of palynomorphs

Slides of Lower Cantwell Formation palynomorphs were borrowed from Dr. Arthur Sweet, Canadian Geological Survey, in 1997. Using the 20x and 40x lenses, and the 100x oil emersion lens on my Zeiss microscope, I reviewed approximately 200 slides from Sweet's (1994a, 1994b)

collections, and chose three slides with abundant palynomorphs to evaluate and analyze for comparative purposes. All the other slides were barren or nearly so.

Preliminary study of palynomorphs

Using my personal Zeiss Axioskop microscope, Model Standard 20, I examined a total of 133 slides from 39 sample horizons within the Matanuska Formation. All of the palynomorphs discussed and figured herein were viewed with a Zeiss Plan-Neofluor 100x/1.30 oil emersion lens and Zeiss Immersionsoel 518C. The data collection process included measuring the grains with an eyepiece reticule. I pencil-sketched and measured selected grains, noted the x and y coordinates of each figured specimen on the stage micrometer, and identified most grains to genus level at 100X under oil, recording the information in notebooks. Palynomorphs from Mazuma Creek, Hicks Creek, Granite Creek, Slide Mt., and Syncline Mt. study sites were documented in this fashion.

During the first six years of this project, I examined the 28 slides produced by Sterrett at ARCO **(Appendix A)** at 40x, 60x and 100x, to record the numbers of genera, sketch and photograph the grains, and do preliminary grain counts, but I did not acquire data on abundances of taxa. In 2003,

prior to my fourth and final evaluation of all my materials, I had 23 additional samples processed by Global Geolabs **(Appendix A)**. During my final evaluation I examined all 51 slides, the original 28 slides processed by ARCO and the 23 new slides processed by Global Geolabs. Using only the 100x lens under oil, I re-located, re-measured, re-photographed, and identified a total of seven fungal spores, 207 spores and 174 pollen grains, and isolated 51 types of wood cells. I was not able to identify the genera of 12 spores and 8 pollen grains.

Photography of palynomorphs

A 35mm Canon EOS RebelG camera attached to the top of my microscope with a photo tube was used to photograph figured grains. Fuji or Kodak black and white ASA100 35mm film was exposed on an automatic setting. I used the 100X oil emersion lens for photographic work at all times. The photos were catalogued by roll number and photo number, and these same numbers were recorded on proof sheets and negatives. This numbering system allows negatives of each grain to be relocated. Photographs were commercially printed on proof sheets for reference.

I worked on slides for one collection site at a time using the following steps. As each roll of negatives was

printed, I separated and numbered each photograph. Then I separated the fungal spores, wood cells, and spores from the pollen grains. Next I sorted the spores, and then the pollen grains, by complexity, starting with the grains that had the least amount of ornamentation and ending with the most complex ornamentation. For each page I made a preliminary layout of the spores and pollen grains on a heavy card stock plate. Then I cut and pasted the photos of the grains into position, scanned each plate into my document using an HP scanner, and labeled each grain with a number. Finally, I composed the corresponding facing pages with the collection sites, the scientific names, and the x and y coordinates of each photographed specimen. Appendices A-J contain 193 photographic plates of the spores and pollen grains from the Matanuska paleoflora.

Production of illustrations

Production and modification of illustrations, including the maps and charts in Chapters One and Two, and Figures 1 through 18, were begun by Ms. Kristi Wallace, using Adobe Illustrator 8.0 software. The lithostratigraphic sections of Mazuma Creek, the primary study site were constructed by Ms. Catherine Vyborny-Carter using Canvas 9.0.4. The vertical section of the Mazuma Creek outcrop, with sample

sites noted **(Fig. 32)**, was hand drafted Lee Reid, Civil Engineer, P.E., who performed the physical survey. The data were converted to a computer illustration by Greg Mitchell. The illustration was later modified by Ms. Vyborny-Carter.

IV. Results

Introduction

The Matanuska Formation represents sediments deposited in a forearc basin that developed adjacent to a volcanic island arc. The lithostratigraphic units that crop out at Mazuma Creek reveal a classic transgressive sequence, with non-marine sediments overlain by marine sediments **(Figs. 14, 35, 39, 46, 47, 51)**. The non-marine units consist of alternating beds of conglomerate, poorly lithified carbonaceous sandstones, blocky sandstones, shale, volcanic ash, and unlithified clay. Cross-bedding seen in poorly lithified carbonaceous sandstone and conglomerate in the nonmarine units suggests deposition as sandbars and channel fill between migrating braided streams (Boggs, 1987) **(Figs. 29, 33, 35)**. Interbedded shale, unlithified clay, carbonaceous sandstone and coal seams almost certainly represent flooded and swampy environments.

Evidence for active volcanism is also present. One small volcanic bomb was found in sample B003, from Mazuma Creek sample site B **(Fig. 35)**, and several layers of volcanic ash were found at sites C004, C006, and D009 **(Figs.**

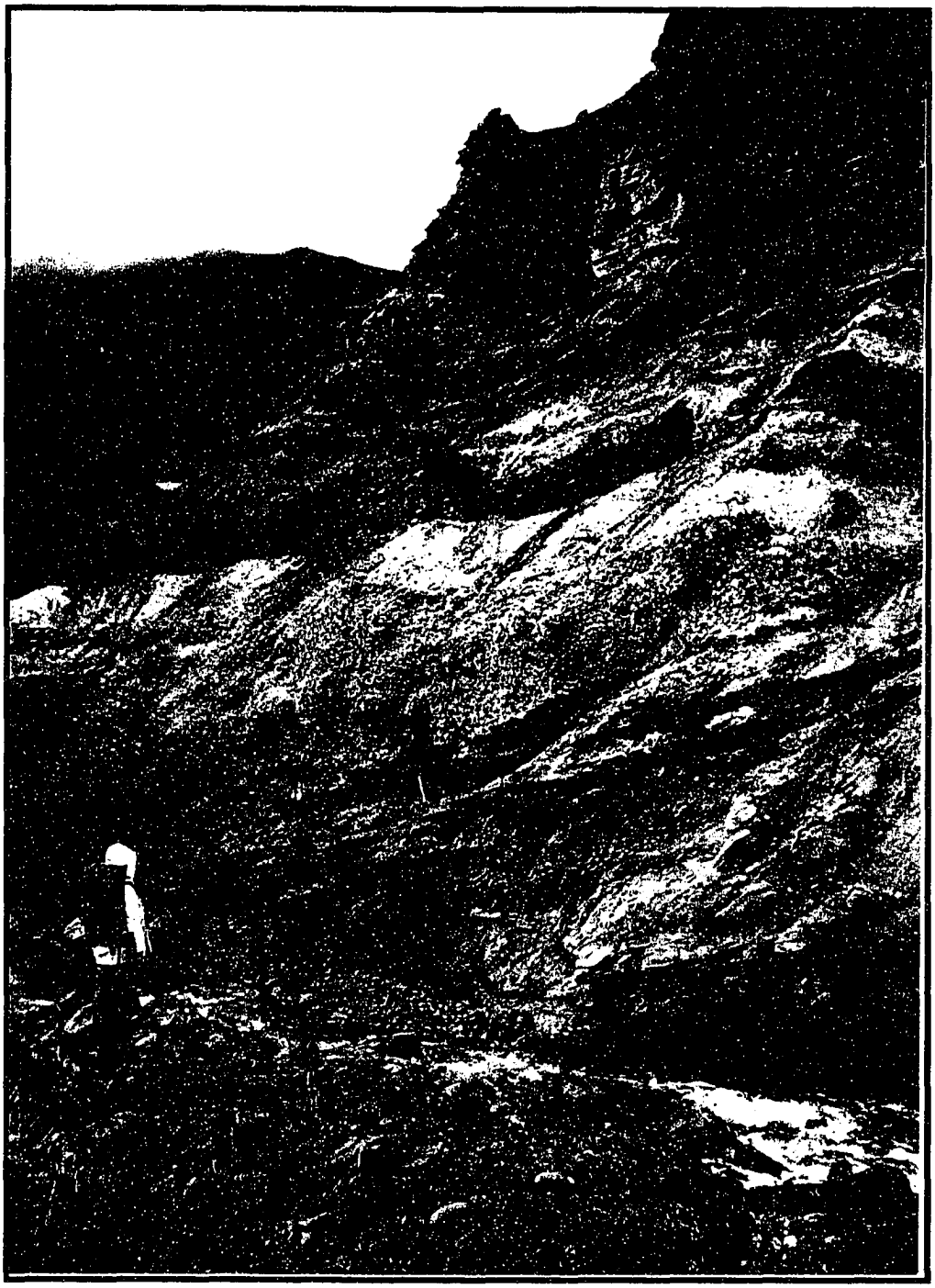

Fig. 51. Outcrop at Pt. O. Marine rocks, top right of photo, conformably overlie conglomerates intercalated with coal seams. Dr. Triplehorn is for scale (Photo by S. Reid).

Fig. 52. Outcrop showing ash seams (arrows) and coal deposits intercalated with conglomerate. Dr. Lee Reid is between sample site D and sample site E-1 (Photo by S. Reid).

36, 37, 52). The ash is interbedded with the nonmarine unit.

Fragile remains of small plants less than 2.5 cm (.5 in) in width and 5-7.5 cm (2-3 in) in height were present in the friable claystone at site C002, **(Fig. 38)**, but the plants disintegrated upon attempt to collect them. Megafossils of *Metasequoia* species and plant fragments including cones, leaflets and wood, were recorded in the more lithified sandstone units.

Fossil vertebrate and invertebrate specimens are present throughout the marine sediments. Several specimens of fish scales were collected by Dr. Triplehorn and two small, nearly complete crabs in marine shale outcrops on the south side of Mazuma Creek were discovered by Dr. Lee Reid, opposite the section between sites E-2 and F.

A small *Dentalium* species was seen at the marine-nonmarine transgressive interface at site F **(Figs. 47, 53)**. Numerous specimens of a *Rhynchonellid* brachiopod were also collected at site F by Dr. Triplehorn. Other mollusks, including several small unidentified pelecypods, gastropods, and inoceramid bivalves were seen throughout the marine section of the Mazuma Creek outcrop. Numerous ammonoids were collected, and one nautiloid recovered in a concretion

Fig. 53. Broad view of site F on Opal Creek. Anne Pasch and Dr. Lee Reid are examining the outcrop at the marine-nonmarine interface for fossil material (Photo by S. Reid).

collected near the top of the marine outcrop on Opal Creek. The recoverable specimens have been accessioned to the University of Alaska Museum of the North in Fairbanks.

Matanuska Formation pollen assemblages compared to assemblages of the *Aquilapollenites* Province

The nonmarine and marine sedimentary sections at the Mazuma Creek site were sampled specifically for pollen and

spore analyses, focusing on the under- and over-clays in association with carbonaceous sandstone and coal seams. At the remaining study sites, Slide Mountain, Syncline Mountain, Hicks Creek, and Granite Creek, only marine rocks were present. Pollen taxa recovered from these five sites **(Map in Pocket, Tables 18, 19, 20)** include the angiosperm genera *Aquilapollenites*, *Oculata*, *Callistopollenites*, *Normapolles*, and *Proteacidites*, the gymnosperm families Taxodiaceae, Cupressaceae, and Taxaceae (TCT), and the gymnosperm genus *Podocarpidites*. Samples from outcrops along Kings River and Moose Creek and from exposures along the Glenn Highway generally were barren.

The Mazuma Creek assemblages

The Mazuma Creek pollen and spore assemblages from sample sites A-F are enumerated by sample site **(Table 21, Appendix A)** and also by florule **(Table 22)**. Florules are pollen assemblages from discreet beds. Sample sites C and D contain the largest numbers of spore genera, 45 and 59 respectively. Sample sites A and D contain the greatest diversity of angiosperm genera, 17 and 26 respectively. Site D contains the greatest diversity of gymnosperm pollen, 14 genera, while site C contains 12 genera, and sites A and

Table 18

Selected pollen groups present in the Matanuska Formation

Site	Angiosperm Groups	Gymnosperm Groups
1. **Mazuma Creek** (Appendices A-F)	*Aquilapollenites* *Callistopollenites* *Wodehouseia* Proteaceae	*Podocarpidites* TCT
2. **Syncline Mountain** (Appendix G)	*Aquilapollenites* *Normapolles*	TCT
3. **Hicks Creek** (Appendix H)	*Aquilapollenites*	*Podocarpidites* TCT
4. **Slide Mountain** (Appendix I)	*Aquilapollenites* *Callistopollenites* *Wodehouseia* Proteaceae	*Podocarpidites*
5. **Granite Creek** (Appendix J)	*Aquilapollenites* *Wodehouseia* *Normapolles* Proteaceae	TCT

F each contain 11 pollen genera, respectively **(Table 23)**. The Mazuma Creek assemblages contain two of the taxa designated by Frederiksen (1987) as representative of the Continental Margin paleoflora, the Proteaceous pollen species *Beaupreadites elegansiformis* and the fern spore genus *Appendicisporites*. The Mazuma Creek assemblages also contain 75 trilete or monolete spore genera. However, the

Table 19

Comparison of numbers of genera of palynomorphs found at the five study sites

Site	Trilete/Monolete Spores	Angiosperm Pollen	Gymnosperm Pollen
Mazuma Creek (Appendices A-F)	75	38	20
Syncline Mountain (Appendix G)	-	8	10
Hicks Creek (Appendix H)	9	2	7
Slide Mountain (Appendix I)	22	14	12
Granite Creek (Appendix J)	-	8	5

Mazuma Creek assemblages also contain an abundance of pollen taxa belonging to the *Aquilapollenites* and *Callistopollenites* Groups, characteristic of the *Aquilapollenites* Province **(Table 1)**.

Rare or absent in Frederiksen's (1987) Continental Margin flora are triporate pollen of Myricaceae, Betulaceae, Juglandaceae, Ulmaceae, and monolete pollen of *Arecipites*

Table 20

Diversity ratios of spore and pollen genera.
T/M refers to trilete and monolete spores.

Site	T/M:Gymnosperms	T/M:Angiosperms	Gymnosperms:Angiosperms
Mazuma Creek (Appendices A-F)	1:0.27	1:0.51	1:1.90
Syncline Mt. (Appendix G)	_	_	1:0.70
Hicks Creek (Appendix H)	1:0.78	1:0.22	1:0.29
Slide Mt. (Appendix I)	1:0.55	1:0.64	1:1.17
Granite Creek (Appendix J)	_	_	1:1.60

(palm). Pollen grains of Myricaceae and Betulaceae are poorly represented in the Matanuska assemblages, and pollen genera of Juglandaceae, Ulmaceae, and *Arecipites* are absent **(Appendices A-F)**.

Mazuma Creek. Seventy-five genera of trilete and monolete (T/M) spores, mostly fern spores, dominate the Mazuma Creek assemblages. Angiosperm palynomorphs, including 17 triprojectate and 2 oculate forms, were second in diversity with 38 pollen genera. Gymnosperm pollen genera numbered 20 (**Tables 18, 19) (Appendices A-F)**. Ratios of fossil spore and pollen diversity are given in **Table 20.**

Table 21

Palynomorphs identified in Mazuma Creek (A-F), Syncline Mountain (G), Hicks Creek (H), Slide Mountain (I), and Granite Creek (J) samples

	FUNGAL SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
1	*Colligerites*	*kutchensis*	X				
2	*Dyadosporites*	*substrangulatus*	X				
3	*Fusiformisporites*	*rugosus*	X				
4	*Palambages*	*canadiana*	X				
5	*Pluricellaesporites*	*magnus*	X				
6	*Pluricellaesporites*	*sheffyi*	X				
7	*Tetraporina*	sp.	X				

	WOOD CELLS	A-F	G	H	I	J
1	cf. *Araucarioxylon*	X				
2	cf. *Ginkgo*	X				
3	cf. *Pinus*	X				
4	cf. *Podocarpus*	X				
5	cf. *Sequoia*	X			X	
6	cf. *Taxodium*	X				
7	Unidentified Wood	X		X	X	

	SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
1	*Acanthotriletes*	*varispinosus*	X				
2	cf. *Anemia*	*paradoxa*	X				
3	*Appendicisporites*	*bilateralis*	X				
4	*A.*	sp.	X				
5	*Aequitriradites*	*spinulosus*	X			X	
6	*Baculatisporites*	*comaumensis*	X				
7	*B.*	spp.	X				
8	*Biretisporites*	*potoniaei*	X				
9	*B.*	*psilatus*	X				
10	*B.*	cf. *potoniaei*	X				
11	*Brevimonosulcites*	*corrugatus*	X				

Table 21 continued

	SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
12	*cf. Brevimonosulcites*	*corrugatus*	X				
13	*Calamospora*	sp.	X				
14	*Camarozonosporites*	*ambigens*	X				
15	*C.*	*australiensis*	X				
16	*C.*	*insignis*	X				
17	*C.*	sp.	X				
18	*Ceratosporites*	*equalis*	X				
19	*C.*	*levidensis*	X				
20	*C.*	*cf. couliensis*	X			X	
21	*Cibotiumspora*	*juncta*	X			X	
22	*C.*	*jurienensis*	X				
23	*Cicatricosisporites*	*augustus*	X				
24	*C.*	*annulatus*	X				
25	*C.*	*hallei*	X				
26	*C.*	*hughesi*	X				
27	*C.*	*imbricatus*	X				
28	*C.*	*ornatus*	X				
29	*C.*	*pseudotripartitus*	X				
30	*C.*	*radiatus*	X				
31	*C.*	spp.	X				
32	*C.*	*cf. annulatus*	X				
33	*C.*	*cf. hallei*	X				
34	*C.*	*cf. imbricatus*	X				
35	*Cingulatisporites*	*reticingulus*	X				
36	*Cingutriletes*	*clavus*	X				
37	*C.*	sp.	X				
38	*Conbaculatisporites*	sp.	X				
39	*Concavisporites*	sp.	X				
40	*Concavissimisporites*	*punctatus*			X		
41	*Concavissimisporites*	*cf. minor*	X				
42	*C.*	spp.	X			X	
43	*Concavitriletes*	*mesozoicus*	X				
44	*Contignisporites*	sp.				X	
45	*Converrucosporites*	sp.	X				
46	*Converrucosisporites*	*cf. cameronii*	X				
47	*Cornutisporites*	*seebergensis*	X				
48	*Cyathidites*	*australis*	X				
49	*C.*	*diaphana*	X				

Table 21 continued

	SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
50	*C.*	*minor*	X				
51	*C.*	spp.	X				
52	*Deltoidospora*	*diaphana*				X	
53	*D.*	*hallii*	X			X	
54	*D.*	*juncta*	X				
55	*D.*	*neddeni*	X				
56	*D.*	*psilostoma*	X				
57	*D.*	spp.	X		X	X	
58	cf. *D.*	*psilostoma*				X	
59	*Dictyophyllidites*	*harrisii*				X	
60	*D.*	*mortonii*	X			X	
61	*D.*	sp.	X				
62	*Distaltriangulisporites*	*maximus*				X	
63	*Distaltriangulisporites*	*mutabilis*	X				
64	*D.*	*perplexus*	X			X	
65	cf. *Duplosporis*	*ocliferius*	X				
66	*Echinatisporis*	*solaris*	X				
67	*E.*	spp.	X				
68	*Echinosporis*	sp.	X				
69	*Foraminisporis*	*simiscalaris*	X				
70	*F.*	*undulatus*	X				
71	*F.*	*wonthaggiensis*	X				
72	*Foveasporis*	*linearis*	X				
73	*F.*	cf. *linearis*	X				
74	*Foveogleicheniidites*	*confossus*	X				
75	*Foveosporites*	*crassus*	X				
76	*F.*	*subtriangularis*	X				
77	*F.*	spp.	X				
78	*Foveotriletes*	*palaequestrus*	X				
79	*Gemmatriletes*	*morulus*	X				
80	*Gleicheniidites*	*circinidites*	X		X	X	
81	*G.*	*concavisporites*	X				
82	*G.*	*delicatus*	X				
83	*G.*	*senonicus*	X				
84	*G.*	*umbonatus*	X			X	
85	*G.*	cf. *circinidites*			X		
86	*G*	cf. *senonicus*	X				
87	*G.*	spp.	X			X	

Table 21 continued

	SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
88	*Hamulatisporis*	*amplus*	X			X	
89	*Hazaria*	*canadiana*	X				
90	*H.*	*sheoparii*				X	
91	*Hymenoreticulisporites*	*castallatus*	X				
92	*Interulobites*	*intraverrucatus*	X				
93	*Klukisporites*	*pseudoreticulatus*	X				
94	*Krauselisporites*	*hastilobatus*	X				
95	*K.*	*reissingerii*	X				
96	*Laevigatosporites*	*gracilis*	X				
97	*L.*	*ovatus*	X				
98	*L.*	spp.	X		X	X	
99	*Leptolepidites*	*crepitus*	X			X	
100	*L.*	*proxigranulatus*				X	
101	*L.*	*verrucatus*	X			X	
102	*Lycopodiacidites*	*canaliculatus*	X				
103	*L.*	*caperatus*	X				
104	*L.*	sp.	X				
105	*Lycopodiumsporites*	*crassatus*	X				
106	*L.*	*crassimacerius*	X				
107	*L.*	*marginatus*	X				
108	*L.*	*singhii*	X				
109	*L.*	spp.	X				
110	*Lygodium*	sp.	X				
111	*Lygodioisporites*	*verrucosus*	X				
112	*Matonisporites*	*crassiangulatus*	X				
113	*Microfoveolatosporis*	*pseudoreticulatus*	X			X	
114	*Microreticulatisporites*	*crassiexinous*	X				
115	*M.*	*diatretus*	X				
116	*M.*	*uniformis*	X				
117	*M.*	sp.	X		X		
118	*Neoraistrickia*	*truncata*	X		X	X	
119	*N.*	spp.	X			X	
120	*Ornamentifera*	*baculata*	X		X		
121	*O.*	*echinata*	X			X	
122	*Osmundacites*	*wellmanii*	X				
123	cf. *Pilosisporites*	*trichopapillosus*	X				
124	*P.*	sp.	X				
125	*Polycingulatisporites*	*reduncus*	X			X	

Table 21 continued

	SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
126	*Polypodiidites*	spp.	X				
127	*Psilatriletes*	*radiatus*	X				
128	*Reticulatasporites*	*dupliexinous*	X				
129	*Reticulisporites*	*semireticulatus*	X				
130	*Reticuloidosporites*	*pseudomurii*	X				
131	*Retitriletes*	*austroclavatidites*	X			X	
132	*R.*	*clavatoides*	X				
133	*R.*	*crassimacerius*	X				
134	*R.*	*lucifer*	X				
135	*R.*	*singhii*	X				
136	*R.*	*subreticulaesporites*	X			X	
137	*R.*	sp.	X				
138	cf. *R.*	*subreticulaesporites*			X		
139	Rouseisporites	*triangularis*	X				
140	*Schizaeoisporites*	sp.	X				
141	*Schizea*	*reticulata*	X				
142	*Selaginella*	*simplex*	X				
143	*Sestrosporites*	*pseudoalveolatus*				X	
144	*Stereiosporites*	*antiquasporites*	X				
145	*Taurocusporites*	*segmentatus*	X				
146	cf. *T.*	*segmentatus*	X				
147	*Todisporites*	*minor*	X				
148	*T.*	sp.	X			X	
149	*Toroisporis*	*delicatus*	X				
150	*Trianchoraeosporites*	*reticulatus*	X			X	
151	*Triplanosporites*	*sinuosus*	X				
152	*Triporoletes*	*radiatus*	X				
153	*Umbosporites*	*callosus*				X	
154	*Undulatisporites*	*fossulatus*	X		X		
155	*Verrucosisporites*	*major*	X				
156	*V.*	spp.	X				
157	Unknown	spp.	X		X	X	X

	POLLEN		A-F	G	H	I	J
	Genus	**Species**					
1	*Abiespollenites*	spp.	X			X	
2	*Abietineaepollenites*	*microreticulatus*	X				

Table 21 continued

	POLLEN		A-F	G	H	I	J
	Genus	Species					
3	*A.*	*varius*	X		X		
4	*A.*	sp.		X			
5	*Abietipites*	sp.	X				X
6	*Accuratipollis*	*evanidtus*	X				
7	*Alisporites.*	*bilateralis*	X		X		
8	*A.*	*grandis*	X		X		
9	*A.*	cf. *bilateralis*	X				
10	cf. *A.*	*bilateralis*		X			
11	*A.*	cf. *microsaccus*			X		
12	*Alnipollenites*	*verus*				X	
13	*A.*	sp.	X				
14	*Alnus*	*incana*	X				
15	cf. *Anacolosidites*	spp.	X				
16	*Aquilapollenites*	*augustus*	X				
17	*A.*	*bertillonites*	X				
18	*A.*	*conatus*	X			X	
19	*A.*	*contiguus*	X				
20	*A.*	*delicatus*	X				
21	*A.*	*delicatus* var. *delicatus*	X			X	
22	*A.*	*notabile*	X	X			
23	*A.*	*polaris*	X			X	
24	*A.*	*quadrilobus*	X				X
25	*A.*	*reticulatus*					X
26	*A.*	*scabratus*	X				
27	*A.*	*senonicus*	X	X			X
28	*A.*	*spinulosus*	X	X		X	
29	*A.*	*trialatus*	X			X	
30	*A.*	sp.	X				
31	*A.*	cf. *delicatus*	X				
32	*A.*	cf. *catenireticulatus*	X				
33	*A.*	cf. *polaris*	X				
34	*A.*	cf. *reticulatus*				X	
35	*Beaupreadites*	*elegansiformis*				X	
36	*Betulaepollenites*	spp.	X			X	
37	*Boehlensipollis*	sp.	X				
38	*Bombacacipites*	spp.					X
39	*Bombacacipites*	cf. *nacimientoensis*	X				

Table 21 continued

	POLLEN		A-F	G	H	I	J
	Genus	**Species**					
40	*Callistopollenites*	*comis*	X				
41	*C.*	*radiostriatus*				X	
42	Cedripites	canadensis	X		X		
43	*C.*	*cretaceus*	X				
44	*C.*	*parvus*				X	
45	*C.*	cf. *parvus*	X				
46	*C.*	spp.	X	X		X	X
47	*Cranwellia*	*rumseyensis*	X				X
48	*C.*	*striata*	X	X			
49	*Cupanieidites*	*major*				X	
50	*C.*	*terrestris*	X				
51	*Cycadopites*	*reticulatus*		X	X	X	
52	*C.*	sp.	X	X			
53	*Dryadopollis*	sp.	X				
54	*Ephedrapites*	spp.	X	X		X	
55	*Erdmanipollis*	*albertensis*	X				
56	*Eucommiidites*	*troedssonii*	X			X	
57	*E.*	*minor*	X				
58	cf. *Expressipollis*	*ocliferus*				X	
59	*Extraporopollenites*	sp.	X				
60	*Extratriporopollenites*	sp.	X	X		X	
61	*Fraxinoipollenites*	*constrictus*	X			X	X
62	*F.*	sp.	X			X	
63	*Ilexpollenites*	*obscuricostata*	X				
64	*Liliacidites*	*inaequalis*	X	X			
65	*Mancicorpus*	*albertensis*		X			
66	*M.*	*canadiana*	X				
67	*M.*	*pulcher*	X				
68	*M.*	*rostratus*		X			
69	*M.*	sp.	X				X
70	*M.*	cf. *trapeziforme*	X				
71	*M.*	cf. *tripodiformis*		X			
72	*Marcellopites*	*basilicus*	X				
73	*Momipites*	*inaequalis*	X				
74	*Myrica*	sp.	X				
75	*Nyssapollenites*	*albertensis*	X			X	
76	*N.*	*bindae*	X				
77	*Nyssoidites*	*anulatus*	X				

Table 21 continued

	POLLEN		A-F	G	H	I	J
	Genus	**Species**					
78	*Oculopollis*	*orbicularis*				X	
79	*O.*	sp.				X	
80	*Parvisaccites*	*radiatus*	X				
81	*P.*	sp.	X				
82	*P.*	cf. *radiatus*	X				
83	*P.*	cf. *rugulatus*	X				
84	cf. *P.*	*amplus*	X				
85	*Penetetrapites*	*inconspicuus*	X				
86	cf. *P.*	*inconspicuus*	X				
87	*Phyllocladites*	cf. *microreticulatus*	X				
88	*Piceapollenites*	spp.	X	X			
89	*Pinuspollenites*	*constrictus*	X				
90	*P.*	spp.	X			X	
91	*Pityosporites*	*alatipollenites*	X				
92	*P.*	*constrictus*	X	X			
93	*P.*	*elongatus* var. *elongatus*				X	
94	*P.*	*elongatus* var. *grandis*	X				
95	*P.*	sp.			X		
96	*P.*	*alatipollenites*					X
97	cf. *P.*	*elongatus* var. *elongatus*					X
98	*Platysaccus*	spp.	X				
99	*Podocarpidites*	*biformis*	X		X		
100	*P.*	*canadensis*	X	X	X		
101	*P.*	*epistratus*				X	
102	*P.*	*granulatus*	X	X	X		
103	*P.*	*minisculus*	X		X	X	
104	*P.*	*multesimus*	X	X	X	X	
105	*P.*	*potomacensis*	X	X			
106	*P.*	*radiatus*	X				
107	*P.*	cf. *canadensis*					X
108	*P.*	cf. *ellipticus*	X				
109	*P.*	cf. *radiatus*	X				
110	*P.*	spp.	X				
111	*Proteacidites*	*auratus*	X	X			
112	*P.*	*retusus*	X			X	
113	*P.*	*thalmanni*	X			X	
114	*P.*	spp.	X			X	
115	cf. *P.*	*retusus*	X				

Table 21 continued

	POLLEN		A-F	G	H	I	J
	Genus	**Species**					
116	*Quercoidites*	*sternbergi*		X			
117	cf. *Quercus*	*explanata*	X				
118	*Retibrevitrocolporites*	*beccus*				X	X
119	*Retitricolpites*	*georgensis*	X				
120	*R.*	*maximus*	X				
121	*R.*	*vulgaris*	X				
122	*Rousea*	*subtilis*	X				
123	*R.*	sp.	X				
124	*Rugubivesiculites*	*reductus*	X			X	
125	*R.*	cf. *reductus*	X	X			
126	*R.*	spp.	X	X		X	
127	*Scollardia*	*trapaformis*	X				
128	*Sequoia*	*papillapollenites*	X			X	
129	*Spermitites*	spp.	X				
130	*Striatellipollis*	*striatella*	X				
131	*Taxodiaceaepollenites*	*hiatus*	X	X		X	X
132	*T.*	*vacuipites*	X				
133	*Tilia*	cf. *wodehousei*	X				
134	*Tricolpate*	spp.			X		X
135	*Tricolpites*	*micromunus*	X				
136	*T.*	*microreticulatus*	X				
137	*T.*	*reticulatus*	X				
138	*T.*	cf. *parvus*	X				
139	*Triprojectate*	sp.			X		
140	*Triporate*	sp.		X			
141	*Triporopollenites*	cf. *mullensis*					X
142	*Trudopollis*	*hemiperfectus*				X	
143	*T.*	*pertrudens*	X				
144	*Ulmoideipites*	*herbridicus*	X				
145	*Vitreisporites*	*pallidus*	X		X	X	
146	*V.*	sp.	X				
147	cf. *V.*	*pallidus*			X		
148	*Wodehouseia*	*capillata*	X				
149	*W.*	*gracile*	X				
150	Unknown	spp.	X				

Syncline Mountain. Seven genera of angiosperm pollen and 10 genera of gymnosperm pollen were recovered from the Syncline Mountain site **(Tables 18, 19, 20, 21).** The ratio of fossil gymnosperm to angiosperm pollen is given in Table 20 **(Appendix G).**

Hicks Creek. Nine T/M spore genera, one tricolpate and one triprojectate angiosperm pollen form, and seven genera of gymnosperm pollen are present in this sample **(Tables 18, 19, 20, 21) (Appendix H).**

Slide Mountain. The dominant palynomorphs from this site include 21 T/M spore genera. Angiosperm pollen is represented by 14 genera, and gymnosperm pollen by 12 **(Tables 18, 19, 20, 21) (Appendix I).**

Granite Creek. The Granite Creek assemblage includes six genera of angiosperms, as well as one tricolpate pollen form and one triporopollenites pollen form, and five genera of gymnosperms **(Tables 18, 19, 20, 21) (Appendix J).**

Volcanic recovery floras in the Mazuma Creek assemblages

Pockets of ash and a volcanic bomb were identified at sample site B-3. Ash layers are also located below sample site C-5, above and below sample site C-6, and within sample site D-9 **(Table 22).** Rock sample D-9 was not processed

because it was lost in transport, but field notes taken at the site document its placement in the outcrop.

The diversity of pollen and spore genera present in the florules reveals a distinct pattern in relationship to the ash layers (**Tables 22, 23**). Before a volcanic event relatively few spore taxa are present relative to pollen taxa. After a volcanic event, fern spore taxa dominate the assemblages. The fern taxa are eventually replaced by taxa representing a low-diversity "weedy" flora and then by taxa representing a dominantly angiosperm flora (Myers, 1996).

A volcanic event is represented by ash at sample site D-9. In D-12, the total number of genera decrease by more than half, and in D-13 the number of spore genera increases from 10 to 17. Gymnosperm diversity remains constant with five genera before and after the event, but the number of angiosperm pollen taxa decreases from 20 genera in D-6 to eight in D-12, then increases upsection to 17 in D-13.

The same pattern is visible at Site B. A fairly large number of spore and pollen genera are present in B-2. The volcanic bomb and pockets of ash are located in B-3, where only four genera of spores and no gymnosperm or angiosperm pollen grains are present. In sample B-4, spore genera triple in diversity to 13, and five gymnosperm and two angiosperm pollen genera are present. This pattern

Table 22

Mazuma Creek angiosperm, gymnosperm and spore generic diversity by florule.
Presence of ash layer below florule sample horizon is indicated by an asterisk.

Florules	Spores	Gymnos	Angios	Wood
A-5	12	4	6	0
A-4	14	3	9	0
A-3*	11	6	7	0
A-2	13	3	4	0
A-1	11	4	7	0
B-5	9	4	2	12
B-4*	13	5	2	0
B-3	4	0	0	0
B-2*	13	5	6	0
B-1*	10	1	5	0
C-6*	no samples			
C-5*	19	6	4	0
C-4	15	4	2	0
C-3	18	5	4	0
C-2	14	2	5	0
C-1	29	5	7	0
D-13	17	5	17	0
D-12*	10	5	8	0
D-6	18	10	20	6
D-4	14	3	11	0
D-1*	4	1	1	2
E-6*	6	2	4	0
E-3*	22	5	5	0
F-5	12	3	5	0
F-4	11	5	5	0
F-3	18	7	0	5
F-2	30	8	2	15

Table 23

Generic diversity of angiosperm and gymnosperm pollen and spores at Mazuma Creek sample sites A through F.

	A	B	C	D	E	F
Angios	17	12	14	26	7	9
Gymnos	11	7	12	14	6	11
Spores	33	29	46	38	21	42

represents a floral recovery following a volcanic disturbance (Myers, 1993, 1996; Myers and Fisher, 1994). Several layers of volcanic ash are present in the overlying nonmarine rocks and palynomorph assemblages found immediately above the ash layers contain a greater number of spore genera and very few to no angiosperm and gymnosperm pollen taxa. As new beds accumulated, the flora recovered and the numbers of angiosperm and gymnosperm pollen genera increased.

Biostratigraphically and geographically significant taxa found in the Matanuska Formation.

As reviewed in Chapters 1 and 2, pollen taxa from the western margins of the CWIS have biostratigraphic and paleogeographic significance **(see summary in Table 24).**

Table 24

First occurrence data of principle CWIS taxa, and geographically endemic pollen taxa characteristic of northern, central and southern regions of the CWIS basin
(modified from Nichols and Sweet, 1993)

First occurrence datums in CWIS	Geographically endemic pollen taxa found at CWIS paleolatitudes		
	North (N) >75° N)	Central (C) (60°-75° N)	South (S) (<60° N)
Uppermost Maastrichtian			
Wodehouseia spinata	(N, C, S) *Wodehouseia pinata*		
Mancicorpus vancampoae		(C) *Mancicorpus vancampoae*	
Upper Maastrichtian			
Wodehouseia gracile	(N) *Wodehouseia quadrispina*		
Mancicorpus rostratus	(N) *Wodehouseia octospina*		
	(N) *Aquilapollenites parallelus*		
	(N) *Aquilapollenites reticulatus*		
	(N) *Triprojectus unicus*		
	(N) *Triprojectus magnus*		
		(C) *Mancicorpus rostratus*	
		(C, S) *Tricolpites microreticulatus*	
			(S) *Tilia wodehousei*
			(S) *Arecipites genus*
			(S) *Liliacidites complexus*
Campanian-Maastrichtian Boundary			
Wodehouseia genus (N, C)			
Kurtzipites genus (C, S)			
Cranwellia rumseyensis			
Mancicorpus tripodiformis			
	(N, C) *Wodehouseia* genus		
Campanian			
Aquilapollenites genus	(N, C) *Azonia* genus		
Mancicorpus genus	(N, C) *Expressipollenites* genus		
		(C) *Aquilapollenites regidus*	
		(C, S) Proteaceous genera	

None of the palynomorph assemblages from the five study sites contain all of the CWIS biostratigraphic index taxa. However, certain other pollen taxa can be used to define the age.

Three of the five Matanuska study sites, Mazuma Creek, Syncline Mountain and Slide Mountain, contain biostratigraphic index taxa which date the assemblages as Late Maastrichtian. Assemblages also contain geographically endemic taxa indicative of paleolatitudes below 75° N **(Table 24)** (Nichols and Sweet, 1993).

Syncline Mountain: Late Maastrichtian, <75° N paleolatitude. Marine rocks of the Syncline Mountain site in the Talkeetna Range were deposited during the Maastrichtian Epoch, probably in a near-shore environment (Grantz and Jones, 1960; Jones, 1963). Grantz (Pers. comm., 1995) considers this to be the youngest section of the Matanuska Formation based on ammonoid and inoceramid fossils. Proximity to land allowed pollen and spores to be carried into the marine basin by fluvial systems, overland sheetflow, wind and rain. The presence of a single grain of *Mancicorpus rostratus* pollen grain suggests that the Syncline Mountain unit is at least Late Maastrichtian in age and was located <75° N paleolatitude (Nichols and Sweet, 1993).

Mazuma Creek: Late Maastrichtian, central CWIS to southern CWIS. Ten pollen species in the Mazuma Creek assemblage indicates a minimum Late Maastrichtian age. They include *Wodehouseia gracile* (Wiggins, 1976), and *Aquilapollenites augustus, A. conatus, A. delicatus* var. *delicatus, A. quadrilobus, Cranwellia rumseyensis, Mancicorpus trapeziforme, Nyssoidites anulatus, Penetetrapites inconspicuus,* and *Striatellipollis striatella,* which are also recognized as Late Maastrichtian in the Coalspur Formation of the Central Foothills of Alberta. The Central Foothills of Alberta are located in the central CWIS region between 60°-75° N paleolatitude (Nichols *et al.*, 1990; Nichols and Sweet, 1993).

Tricolpites microreticulatus, also found in the Mazuma Creek assemblage, is common in upper Maastrichtian rocks of the central and southern CWIS (Nichols and Sweet, 1993). One specimen of *Tilia* cf. *wodehousei* was found in the Mazuma Creek assemblage. This taxon, first identified in latest Maastrichtian rocks of the Raton Basin, New Mexico (Anderson, 1960), in the southern CWIS, is rare or unknown to the north of the Raton Basin (Nichols and Sweet, 1993). Thus the specimen of *T. wodehousei* suggests the Matanuska

flora lay near the boundary of the central and southern CWIS (60° N) during Late Maastrichtian time.

Slide Mountain: Late Maastrichtian, <75° N. Rocks at this site are characterized as deep marine based on sedimentology and invertebrate fossils. Bathyal depth of the marine basin is suggested by the presence of the ammonite *Pachydiscus kamishakensis*, found in association with several deep-water ammonite species, including *Phyllopachyceras forbesianum*, *Pseudophyllites indra*, and *Gaudryceras tenuiliratum* (Scott, 1940). The non-marine paleomicroflora is most likely derived from pollen rain. This assemblage contains three pollen taxa restricted to the Late Maastrichtian including *Aquilapollenites conatus*, *A. delicatus* var. *delicatus*, and *Retibrevitricolporites beccus* **(Table 9)**, plus one spore species, *Hazaria sheoparii*, found at the Cretaceous-Tertiary boundary in the Coalspur Formation (Jerzykiewicz and Sweet, 1986).

One specimen of *Aquilapollenites* sp. cf. *A. reticulatus* indicates a paleolatitude of 60°-75° N (Nichols and Sweet, 1993) while *A. conatus* and five species Proteaceous pollen, including *Beaupreadites elegansiformis*, *Proteacidites retusus* and *P. thalmanni*, also suggest a correlation with the Late Maastrichtian assemblages from in Saskatchewan

(<60° N paleolatitude) (Nichols and Sweet, 1993). One specimen of the *Normapolles* Group, *Trudopollis hemiperfectus* is also present. Pollen grains of the *Trudopollis* genus are common in Latest Maastrichtian rocks of the Raton Basin, New Mexico and are reported throughout the central (60°-75° N paleolatitudes) and southern (<60° N paleolatitude) regions of the CWIS (Nichols and Sweet, 1993). No *Trudopollis* species are reported in the Bonnet Plume Formation, Yukon Territory (Sobczak and Long, 1980), or the East Fork Formation, Northwest Territories (Yorath and Cook, 1981). Both these regions were located at >75° N paleolatitude. Frederiksen *et al.*, (1987), however, report two species of *Trudopollis* in Late Maastrichtian rocks of the North Slope of Alaska, >75° N paleolatitude (Nichols and Sweet, 1993), although Frederiksen (1989) considers them to be rare and of very low diversity. Rare occurrences of *Trudopollis* species in the Slide Mountain assemblages thus suggest paleolatitudes greater than 60° N for this portion of the Matanuska Formation.

Granite Creek: Late Maastrichtian, <60° N. The presence of the Late Maastrichtian pollen species *Aquilapollenites quadrilobus*, *Cranwellia rumseyensis* and *Retibrevitricolporites beccus* (Jerzykiewicz and Sweet, 1986) date the Granite Creek section as Late Maastrichtian.

Retibrevitricolporites beccus has been identified in Colorado in the uppermost Maastrichtian strata of the Laramie Formation (Nichols and Sweet, 1993). Colorado is located in the southern regions of the CWIS, at <60° N paleolatitude.

Hicks Creek: Campanian. This unit has been previously identified as Campanian by Grantz and Jones (1960). A single unidentified triprojectate pollen grain in the Hicks Creek assemblage is consistent with a Campanian age. There are no pollen taxa present that are diagnostic of paleolatitudes.

Although the Matanuska assemblages contain Campanian-Maastrichtian index taxa, coeval taxa of Late Maastrichtian date the Mazuma Creek, Granite Creek, and Slide Mountain outcrops as Late Maastrichtian. Pollen taxa geographically endemic to the central and southern CWIS, and also found in the Matanuska assemblages, indicate that the Matanuska Formation was deposited at latitudes parallel to the boundary of the central and southern CWIS (60° N).

Biostratigraphically and geographically significant taxa found in the Prince Creek and Cantwell Formations

Prince Creek Formation: Late Maastrichtian, >75° N. The Prince Creek paleomicroflora contains the Late

Maastrichtian pollen taxon *Wodehouseia gracile*. Three pollen taxa, *Wodehouseia quadrispina, Wodehouseia octospina,* and *Triprojectus unicus* (Wiggins, 1976; Frederiksen, 1987), indicate that the Prince Creek Formation was deposited at latitudes >75° N **(Table 25)**.

Cantwell Formation: Campanian-Maastrichtian, 60°-75° N. The Cantwell paleomicroflora contains one biostratigraphic index taxon, *Cranwellia rumseyensis*, which first appears at the Campanian-Maastrichtian boundary in the Bearpaw Formation of Alberta and Montana (<60° N paleolatitude) (Nichols and Sweet, 1993).

The Cantwell paleomicroflora also contains several species of *Aquilapollenites*: *A. quadrilobus, A. reticulatus, A. parallelus,* and *A. trialatus* (Ridgway *et al.*, 1997). *A. quadrilobus* is present by the early Late Campanian in Montana and Wyoming (<60° N paleolatitude) **(Fig.10)** (Nichols and Sweet, 1993). By the Late Maastrichtian it is found farther north in the Coalspur Formation of southwest Alberta (<60° N paleolatitude) **(Fig. 10)** (Jerzykiewicz and Sweet, 1986), and in Late Maastrichtian rocks near the Colville River, on the North Slope of Alaska (>75° N paleolatitude) (Frederiksen, 1991) **(Fig. 10)**. *A. reticulatus* is common in the central

Table 25

Prince Creek Formation

Biostratigraphically and paleogeographically significant taxa of the Prince Creek Formation
(modified from Wiggins, 1976; Frederiksen, 1987)

First occurrence data	**Geographically endemic pollen taxa**		
	North (N) (>75° N)	Central (C) (60°-75° N)	South (S) (<60° N)
Late Maastrichtian			
-*Wodehouseia gracile*	(N) *Wodehouseia quadrispina* (N) *Wodehouseia octospina* (N) *Triprojectus unicus*		

(60°-75° N) and southern CWIS regions (<60° N) and first appears in Upper Campanian rocks of Montana (Tschudy and Leopold, 1971) **(Fig. 10)**. Its range is limited to the Late Maastrichtian

and Early Paleocene at higher paleolatitudes in central Alberta (<60° N paleolatitude) (Jerzykiewicz and Sweet, 1986) where its occurrence is very rare (Nichols and Sweet, 1993). North of Alberta, in the Northwest Territories (60°-75° N paleolatitude), *A. reticulatus* is found only in Maastrichtian rocks (Nichols and Sweet, 1993) **(Table 9)**, while on the North Slope of Alaska (>75° N paleolatitude), *A. reticulatus* is restricted to the Late Maastrichtian (Frederiksen, 1991).

A. parallelus is found in the northern CWIS regions (>75° N), including Upper Cretaceous rocks on the Nation River north of Eagle (Tschudy, 1969) and Upper Maastrichtian rocks of the Bonnet Plume Formation, Yukon Territory (>75° N paleolatitude). This species is also present in the north-central ranges of the CWIS, including most of the Northwest Territories (60°-75° N paleolatitudes) (Nichols and Sweet, 1993).

A. trialatus occurs earliest in the middle Campanian of Montana and in the Middle to Late Campanian of southern Alberta (<60° N paleolatitude); it is present in the northern regions of the CWIS (>75° N), including Late Cretaceous rocks of the Colville Group (Tschudy, 1969), only during the Late Maastrichtian (Nichols and Sweet, 1993) **(Table 26)**. The Cantwell paleomicroflora thus is most similar to the Campanian-Maastrichtian age paleomicroflora of the central and northern regions of the southern CWIS (>60° N paleolatitude), Montana and southern Alberta.

Indications of humid and tropical maritime paleoclimates

The Matanuska Formation palynomorphs present several sets of paleoclimate indicators. The two more prominent groups of pollen and spore species represent either a humid climate or tropical maritime climate **(Table 27)**. The third

Table 26

Cantwell Formation

Biostratigraphically and paleogeographically significant taxa of the Cantwell Formation
(modified from Ridgway *et al.*, 1997)

First occurrence data at time boundaries in CWIS	**Geographically endemic pollen taxa found parallel to CWIS paleolatitudes**		
	North(N) (>75° N)	Central(C) (60°-75° N)	South(S) (<60° N)
Late Maastrichtian			
none present			
		(N) *Aquilapollenites parallelus*	
		(N) *Aquilapollenites reticulatus*	
Campanian-Maastrichtian			
-Cranwellia rumseyensis		(N, C) *Wodehouseia* genus	

set of palynomorphs, which includes the *Aquilapollenites* and *Callistopollenites* Groups, present an opposing set of data suggesting an arid climate **(Table 27)**.

Hicks Creek. Spore taxa which provide paleoclimatic information for this assemblage include 11 species of T/M (fern) spores, particularly two species of *Gleicheniidites*, a genus which is generally associated with swampy, tropical rainforests environments (Brenner, 1963). *Concavissimisporites punctatus* is also indicative of a tropical rain forest (Brenner, 1963), as is

Table 27
Matanuska Formation

Biostratigraphically and paleogeographically significant taxa of the Matanuska Formation
(Jerzykiewicz and Sweet, 1986; Nichols and Sweet, 1993)

First occurrence data	Geographically endemic pollen taxa		
	North (N) (>75° N)	Central (C) (60°-75° N)	South (S) (<60° N)
Latest Maastrichtian			
-no representative taxa present			
Late Maastrichtian			
1. **Syncline Mountain**			
- Mancicorpus rostratus		(C,S) *Mancicorpus rostratus*	
2. **Mazuma Creek**			
- *Aquilapollenites augustus*			
- *A. conatus*		(C,S) *Tricolpites micro-reticulatus*	
- *A. delicatus* var. *delicatus*			
- *A. quadrilobus*			
- *Cranwellia rumseyensis*			
- Hazaria sheoparii			(S) *Tilia* cf. *wodehousei*
- *Mancicorpus rostratus*			
- *M. trapeziforme*			
- *Nyssoidites anulatus*			
- *Penetetrapites inconspicuus*			
- *Retibrevitricolporites beccus*			
- *Striatellipollis striatella*			
- *Tricolpites microreticulatus*			
- *Tilia wodehousei*			
- *Wodehouseia gracile*			
3. **Slide Mountain**	(N) *Aquilapollenites* cf. *reticulatus*		
- *Aquilapollenites conatus*		(C,S) *Trudipollis hemiperfectus*	
- *A. delicatus var. delicatus*			(S) *A. conatus*
- *Retibrevitricolporites beccus*			*Beaupreadites elegansiformis*
- *Hazaria sheoparii*			*Proteacidites retusis*
			P. thalmanni
4. **Granite Creek**			
- *Aquilapollenites quadrilobus*			(S) *R. beccus*
- *Cranwellia rumseyensis*			
- *Retibrevitricolporites beccus*			
Campanian-Maastrichtian			
- no representative taxa present			
Mid-Campanian			
5. **Hicks Creek**			
- Triprojectate form	(N) Aquilapollenites genera		(S) Proteaceous genera

Laevigatosporites, a spore which could represent either a sphenopsid (horsetail) or *Pecopteris* (a tree fern), both of which prefer swampy environments (Traverse, 1988). Pollen species of *Podocarpidites* (an Austral conifer) and a Cycad/Ginkgo taxon (non-coniferous gymnosperm) have Gondwanan affinities and therefore suggest a very warm and humid climate (White, 1990) **(Table 28)**.

Mazuma Creek. Paleoclimate indicators recovered from the Late Maastrichtian outcrops at Mazuma Creek include at least four species of *Proteacidites* (flowering angiosperm shrubs) and abundant T/M spores (75 genera) representing ferns, club mosses and tree ferns **(Appendix A-F)**. Combined with abundant TCT pollen (gymnosperms), these taxa suggest a warm, humid, marshy environment (Srivastava, 1970) **(Table 28)**. The marine overlap at Mazuma Creek clearly defines a shoreline and therefore supports the interpretation of a maritime environment **(Fig. 53)**.

Significant Gondwanan elements, including three genera of *Podocarpidites* and two genera of *Platysaccus* (pollen of *Dicroidium*, a seed fern) (Traverse, 1988) further support the warm, humid paleoclimatic interpretation (Douglas and Williams, 1982).

Table 28

Paleoclimatic significance of the Matanuska paleoflora palynomorphs

Tropical Maritime (Continental Margin) (blue) (Crickmay and Pocock, 1963; Srivastiva, 1970; Frederiksen, 1987)	**Humidity (wet)** (green) Srivastava, 1970)	**Aridity (dry)** (red) Srivastava, 1970; Frederiksen, 1987;Wolfe and Upchurch, 1987; Traverse, 1988; McIver *et al.*, 1991)
Late Maastrichtian		
1. Syncline Mountain	4 *Podocarpidites* spp.	6 *Aquilapollenites* Group spp.
1 *Proteacidites* sp.	1 *Normapolles* sp.	1 *Callistopollenites*
	Metasequoia/TCT	
2. Slide Mountain	3 *Gleicheniidites* spp.	6 *Aquilapollenites* spp.
41 T/M spore spp.	3 *Podocarpidites* spp.	2 *Callistopollenites* Group spp.
5 *Proteacidites* spp.	3 *Normapolles* spp.	
1 *Cupanieidites* sp.	*Metasequoia*/TCT	
2 *Beaupreadites* spp.	1 *Nyssapollenites* sp.	
3. Granite Creek	2 *Bombacacipites* spp.	4 *Aquilapollenites* Group spp.
none	1 *Normapolles* sp.	1 *Callistopollenites* Group sp.
	Metasequoia/TCT	
	1 *Podocarpidites* sp.	
4. Mazuma Creek	9 *Gleicheniidites* spp.	21 *Aquilapollenites* spp.
203 T/M spore spp.	12 *Podocarpidites* spp.	2 *Callistopollenites* Group spp.
5 *Proteacidites* spp.	1 Normapolles sp.	
1 *Cupanieidites* sp.	2 *Nyssapollenites* spp.	
2 *Appendicisporites* spp.	1 *Nyssoidites* sp.	
	Metasequoia/TCT	
Campanian		
5. Hicks Creek	5 *Podocarpidites* spp.	
12 trilete spore spp.	Cycad/Ginkgo	

Wood cells are common in the Matanuska palynoflora assemblage. Based on pit structures, resin ducts and tracheid cells (Tidwell, 1998), six of these are tentatively identified: the *Ginkgo cellular* structure shows highly variable sizes of tracheids (Tidwell, 1998) and uniserate, spaced tracheid pits (Kvaćek *et al.*, 2005); the *Araucarioxylon* wood contains honeycombed, bordered pits (Tidwell, 1998); the *Podocarpus* wood cells displays Podocarpoid cross-field pits (Tidwell, 1998); the *Pinus* fragment contains horizontal and longitudinal resin ducts, and single rows of bordered pits (Tidwell, 1998); the *Taxodium* specimen has Taxodioid cross-field pits (Tidwell, 1998); and the *Sequoia* wood fragment has separated, broad-bordered pits in single columns (Tidwell, 1998). *Ginkgo*, *Araucarioxylon*, *Sequoia*, *Taxodium* and *Podocarpus* wood suggest a warm, humid climate, while *Pinus* indicates a more upland source that was warm but relatively dry **(Appendix A)** (Tidwell, 1998).

Granite Creek. Species of *Bombacacipites* (Allaby, 1992) and *Podocarpidites* (Traverse, 1988) indicate a tropical humid climate for this site. The species *Taxodiaceaepollenites hiatus* is associated with swamps (Tschudy and Scott, 1969), and *Trudopollis hemiperfectus* may

be allied with the warmth loving Juglandales (walnut trees) and swamp-associated Myricales (Wax Myrtle and Sweet Gale shrubs) (Fernald, 1950; Traverse, 1988).

Slide Mountain. Pollen and spore taxa indicative of a continental margin maritime (Grantz, Pers. comm. 1995) climate include 41 T/M spore species, five species of *Proteacidites* pollen, and two species of *Beaupreadites* pollen. This assemblage also contains one species of *Cupanieidites,* which belongs to the Normapolles Group, three species of *Podocarpidites* pollen, and numerous TCT pollen, all of which strongly suggest a humid environment **(Table 28)** (Srivastava, 1970; Frederiksen, 1987; Herngreen *et al.*, 1996).

The Slide Mountain palynomorph assemblage contains several different types of wood cells **(Appendix I)**, including one specimen tentatively identified as *Sequoia,* which prefers warm, well-watered environments (Tschudy and Scott, 1969).

Syncline Mountain. Maritime paleoclimate indicators from the Syncline Mountain assemblage include one genus of *Proteacidites,* five genera of *Podocarpidites,* one genus of *Cycadopites,* and numerous TCT pollen grains **(Table 28)** (Srivastava, 1970; Frederiksen, 1987). These pollen taxa

are also representative of a warm, humid environment (Srivastava, 1970).

Pollen Groups indicative of aridity

The pollen taxa which suggest arid environments belong to the *Aquilapollenites* and *Callistopollenites* Groups **(Table 28)** (Srivastava, 1970; Frederiksen, 1987; Wolfe and Upchurch, 1987; Traverse, 1988; McIver *et al.*, 1991). The five study sites contain numerous representatives of these two groups, but they are far less diverse, and thus are outranked by the larger numbers of palynoflora that represent humid and continental margin paleofloras.

Summary

Pollen assemblages from the Matanuska Formation contain limited but useful elements indicating that the Matanuska Formation was deposited during the Late Maastrichtian south of 75° N paleolatitude. The pollen and spore assemblages from the study sites indicate a mix of tropical maritime, humid, and arid upland elements.

One interpretation of the intermingled paleoclimate indicators is that the maritime continental margin elements of the Matanuska paleoflora may have first been established

on the Talkeetna Island Arc system in tropical paleoclimatic conditions at more southern latitudes near present-day Oregon. As the volcanic island arc system was transported northward within the Peninsular Terrane package the paleoflora must have mingled with elements of the cooler and drier *Aquilapollenites* Province as it was carried northward.

V. Age, Paleolatitude and Climate Interpretations of the Matanuska Paleomicrofloras

Introduction

The Matanuska paleoflora represents the intersection of two paleofloral provinces. Paleomicrofloral assemblages extracted from the five Matanuska Formation study sites contain taxa characteristic of both the Continental Margin Province (Frederiksen, 1987) and the *Aquilapollenites* Province **(Fig. 1)**. The most abundant taxa are monolete and trilete fern spores, followed by angiosperm pollen, and bisaccate and monolete gymnosperm pollen.

Campanian-Maastrichtian assemblages from southcentral, interior, and northern Alaska were examined for the presence of biostratigraphically and geographically significant taxa. Comparisons with CWIS assemblages (Nichols and Sweet, 1993) indicate that the Matanuska Seaway was located south of 75° N latitude during the Late Maastrichtian.

Although separated by several hundred kilometers from outcrops of the Matanuska Formation in the Talkeetna Mountains, the Chignik and Kaguyak paleofloral assemblages extracted from sedimentary rocks of the Late Cretaceous Alaska Peninsula (Wiggins, 1976, 1988; Magoon *et al.*, 1980; Mancini *et al.*, 1978) contained very similar paleofloral

assemblages. If assemblages from the Alaska Peninsula are combined with the Matanuska Formation assemblages, a total of 31 species of triprojectate pollen are present. This combined number is greater than the total number of triprojectate species found in the Colville Group of Arctic Alaska **(Tables 29, 30)**. Based on the diversity of triprojectate pollen, the Prince Creek, Lower Cantwell and Matanuska paleofloras can all be considered characteristic of the *Aquilapollenites* Province **(Table 23)**.

However, the Matanuska paleoflora also contains more than half of the taxa diagnostic of the Continental Margin Province, including species of the fern spore genera *Appendicisporites* and *Cicatricosisporites* **(Appendices A-K)**, and nine of the 17 pollen genera recorded in the Continental Margin Province (**Table 31**). Thus the Matanuska paleoflora is similar to Frederiksen's (1987) Continental Margin Province, which is dominated by spores of *Appendicisporites* and *Cicatricosisporites* and pollen grains of *Proteacidites*. Yet, the Matanuska paleoflora also contains abundant pollen of the *Aquilapollenites* and *Callistopollenites* Pollen Groups which are rare to absent in the Continental Margin Province (**Table 25**). Therefore, I interpret the Matanuska paleoflora to be a transitional flora incorporating taxa of the West

Table 29

Species of triprojectate pollen from the Prince Creek, Lower Cantwell, Matanuska and Alaska Peninsula paleofloras

(Tschudy, 1969; Wiggins, 1976, 1988; Greisbach *in* Magoon *et al.*, 1980; Frederiksen, 1989, 1990; Sweet, 1994a, 1994b; Ridgway *et al.*, 1997)

Species Name	Prince Creek Fm.	L. Cantwell Fm.	Matanuska Fm.	Alaska Pen.
1. *Aquilapollenites* aff. *A. abscisus*	X			
2. *Aquilapollenites alaskensis*	X			
3. *Aquilapollenites amicus*	X			
4. *Aquilapollenites aptus*		X		
5. *Aquilpollenites attenuatus*		X		X
6. *Aquilapollenites* cf. *augustus*	X		X	
7. *Aquilapollenites bertillonites*			X	
8. *Aquilapollenites cateniretículatus*				X
9. *Aquilapollenites clairireticulatus*		X	X	
10. *Aquilapollenites conatus*	X		X	
11. *Aquilapollenites contiguus*		X	X	
12. *Aquilapollenites delicatus*	X		X	
13. *Aquilapollenites delicates* var. *delicatus*				X
14. *Aquilapollenites drumhellerensis*		X		
15. *Aquilapollenites fusiformis*	X	X		
16. *Aquilapollenites immiser*	X			
17. *Aquilapollenites notabile*			X	
18. *Aquilapollenites parallelus*		X		X
19. *Aquilapollenites polaris*			X	
20. *Aquilapollenites quadrilobus*	X	X	X	X
21. *Aquilapollenites rigidus*		X		
22. *Aquilapollenites reticulatus*	X		X	
23. *Aquilapollenites rectus*		X		
24. *Aquilapollenites regalis*		X		
25. *Aquilapollenites reticulatus*		X		
26. *Aquilapollenites scabridus*		X	X	
27. *Aquilapollenites senonicus*	X	X	X	X
28. *Aquilapollenites spinulosus*			X	
29. *Aquilapollenites sp. A*	X		X	
30. *Aquilapollenites trialatus*		X	X	
31. *Aquilapollenites turbidus*		X		X
32. *Aquilapollenites unicus*	X			
33. *Aquilapollenites venustus*		X		
34. *Bratzevaea amurensis*	X			
35. *Fibulapollis inaequalis*	X			
36. *Fibulapollis mirificus*		X		X
37. *Fibulapollis scabratus*	X			
38. *Mancicorpus albertensis*			X	
39. *Manciporpus anchoriforme*	X			X
40. *Mancicorpus* sp.			X	
41. *Mancicorpus borealis*			X	
42. *Mancicorpus canadiana*			X	
43. *Mancicorpus delicatus*	X			
44. *Mancicorpus notabile*	X		X	
45. *Mancicorpus pseudosenonicus*	X			
46. *Mancicorpus pulcher*			X	
47. *Mancicorpus rostratus*	X		X	
48. *Mancicorpus* cf. *Trapeziforme*			X	
49. *Mancicorpus* cf. *tripodiformis*			X	
	21	18	24	9

Table 30

Comparison of numbers of species of oculate pollen, Campanian and Maastrichtian, from the Prince Creek, Lower Cantwell, Matanuska and Alaska Peninsula Paleofloras
(Tschudy, 1969; Wiggins, 1976, 1988; Mancini *et al.*, 1978; Greisbach *in* Magoon *et al.*, 1980; Frederiksen, 1989, 1990; Sweet, 1994 a, b)

Species Name	Prince Creek Fm.	L.Cantwell Fm.	Matanuska Fm.	Alaska Peninsula
1. *Azonia calvata*				X
2. *Azonia* cf. *A hirsuta*	X			
3. *Azonia cribrata*	X			
4. *Azonia fabacea*	X	X		X
5. *Azonia hirsuta*	X			
6. *Azonia parva*	X	X		X
7. *Azonia pulchella*	X			X
8. *Azonia recta*				X
9. *Azonia reticulata*				X
10. *Azonia rugulos*				X
11. *Azonia strictiparva*	X			
12. *Azonia sufflata*		X		X
13. Wodehouseia asper	X			
14. Wodehouseia avita				X
15. *Wodehouseia bella*	X			
16. *Wodehouseia capillata*			X	X
17. *Wodehouseia edmontonicola*	X			
18. *Wodehouseia elegans*	X			
19. *Wodehouseia fimbriata subsp. constricta*	X			
20. *Wodehouseia gracile*	X		X	
21. *Wodehouseia octospina*	X			
22. *Wodehouseia quadrispina*	X			
23. *Wodehouseia spinata*	X			X
24. *Wodehouseia stanleyi*	X			
25. *Wodehouseia vestivirgata*	X			
26. *Wodehouseia wigginsii*	X			
Subtotals: Oculate Pollen	19	3	2	11
Triprojectate Pollen	21	18	24	9
TOTALS: *Aquilapollenites Group*	40	21	26	20

Pacific Rim Continental Margin Province and the North American *Aquilapollenites* Province.

Table 31

Typical pollen taxa included in the Continental Margin and Nanaimo paleofloras compared to the Matanuska paleoflora (modified from Frederiksen, 1987; Crickmay and Pocock, 1963)

Continental Margin paleoflora (Frederiksen, 1987)	**Nanaimo paleoflora** (Crickmay and Pocock, 1963)	**Matanuska paleoflora**
Appendicisporites	*Appendicisporites*	*Appendicisporites*
Arecipites		
Betulaepollenites		*Betulaepollenites*
Cicatricosisporites	*Cicatricosisporites*	*Cicatricosisporites*
	Classopollis	
Cupanieidites		*Cupanieidites*
Cupuliferoidaepollenites		
Cyrillaceaepollenites		
Horniella		
Ilexpollenites		*Ilexpollenites*
Liliacidites		*Liliacidites*
"Plicapollis" thornei		
Proteacidites	*Proteacidites*	*Proteacidites*
Punctatricolpites		
Quercoidites		*Quercoidites*
Sparganiaceaepollenites		
Tricolpites	*Tricolpites*	*Tricolpites*
Triporites		*Triporites*
Triporopollenites		*Triporopollenites*
Syncolpites		

Evaluation of Alaskan paleofloras also resulted in a clearer definition of regional paleoclimates during the Late Cretaceous. Gondwanan microfloral elements found in the Matanuska paleoflora are indicative of a subtropical climate for the Talkeetna Island Arc setting. These microfloral assemblages provide support for earlier geological (Jones, 1963) and geophysical reconstructions (Hillhouse, 1987; Hillhouse and Coe, 1994) of paleolatitudes for southcentral, interior and Arctic Alaska.

Continental margin taxa

Pollen of the *Aquilapollenites* and Oculata Groups are both typical of the *Aquilapollenites* Province. But one of the principle differences between Late Cretaceous paleofloras of the southcentral Matanuska Formation, compared to the interior Cantwell Formation and the Arctic Prince Creek Formation is the diversity of pollen species in the *Aquilapollenites* and Oculata Groups **(Table 1)**. The Prince Creek paleoflora contains 21 species of triprojectate pollen and 19 species of oculate pollen **(Tables 29, 30)**. The Lower Cantwell paleoflora contains 18 species of triprojectate pollen and three species of oculate pollen **(Tables 29, 30)**. Although the Matanuska Paleoflora contains 24 species of triprojectate pollen, most are represented by only one, two, or several grains. Only two species of the oculate pollen genus *Wodehouseia* **(Table 30)** are present. However, *Wodehouseia gracile* is present in most of the assemblages **(Appendices A-K)**. The Chignik paleoflora from the Alaska Peninsula contains three species of *Wodehouseia* (Wiggins, 1976), one of which, *W. capillata*, is also found in the Matanuska paleoflora.

The Prince Creek pollen assemblages contain 14 species of oculate pollen not found in the Matanuska paleoflora,

whereas the Matanuska and Alaska Peninsula oculate pollen assemblages together contain nine species not found in the Prince Creek assemblages. Ultimately, the Prince Creek paleofloras contain a total of 19 oculate pollen species compared to 11 oculate species in the southcentral Alaska assemblages: the two paleofloras share only four species. I interpret the greater number of oculate *Wodehouseia* pollen species in the Prince Creek paleofloras to reflect a cooler Arctic climate, while the greater number of triprojectate pollen species in southcentral Alaska represent a warmer climate.

Volcanic arc vegetation

The Matanuska Formation is situated within the Talkeetna Island Arc system. Thus, environmental stresses associated with volcanism must have modified the Matanuska paleoflora. Sample sites B, C and D **(Figs. 32, 35-40; Table 22)** contain spore data that record "prevolcanic events" below volcanic ash or bombs and initial recovery phases (Myers, 1993, 1996) in florules from sample sites above the ash layers.

Volcanic activity within the Talkeetna Island Arc system is documented by ash layers and pyroclastics in the

Mazuma Creek outcrop **(Fig. 16 and Fig. 17)**. The abundance and diversity of fern spore taxa is consistent with repeated eradication of the vegetation by volcanic activity. There is no evidence, however, that any of these assemblages are dominated by a single species of fern spore.

Gondwanan elements in Matanuska pollen assemblages

The Matanuska paleoflora contains a large number of microfloral genera that apparently have been derived from Gondwanan ancestral stock. Taxa with Gondwanan affinities include the pollen taxa *Proteacidites*, *Podocarpidites*, many species of the Taxodiaceae-Cupressaceae-Taxaceae (TCT) pollen group, *Ephedrapites* pollen, cycad pollen, pollen of several *Platysaccus* genera, and spores of some pteridophyte genera. These Gondwanan floral elements imply that the Matanuska Formation accumulated in a tropical to subtropical climate.

Comparison of the Cantwell paleomicroflora to the Matanuska paleomicroflora

Sweet (1994a, 1994b) studied and reported on the Lower Cantwell Formation pollen assemblages recovered from Late Campanian-Maastrichtian age rocks at Polychrome Pass in Denali National Park and Preserve. He identified 17 species

of *Aquilapollenites*, three species of *Azonia* (**Tables 29 and 30**), one species of *Cranwellia*, one species of *Platanus* (sycamore), and one species of *Kurtzipites*. These species are typical of the *Aquilapollenites* Province. Other species in the Lower Cantwell are indicative of a more tropical to subtropical flora, including pollen of *Arecipites* (palm), *Liliacidites* (lily), and *Ginkgo*. Abundant bisaccate and TCT pollen grains were found in only one sample, but sparse grains are present in nearly all samples.

Sweet (1994a) reported "very abundant" pollen of *Ginkgo* and "abundant" pollen of TCT in one florule, and no species of *Proteacidites* pollen grains in the Lower Cantwell Paleoflora, and relatively few species of the Oculuta, *Callistopollenites* and *Aquilapollenites* Groups compared to the Prince Creek paleoflora. Only 13 genera of trilete spores (Sweet, 1994a, 1994b) are reported in the Lower Cantwell paleoflora. Based on the abundance of *Ginkgo* and TCT pollen in at least one horizon, and the limited presence of bisaccate pollen and trilete spores throughout the Lower Cantwell Formation, and the absence of Proteaceous pollen (Crickmay and Pocock, 1963; Frederiksen, 1987) I consider this assemblage to represent an inland flora.

Comparison of the Prince Creek paleomicroflora to the Matanuska paleomicroflora

The Prince Creek paleoflora is the highest latitude paleoflora of Campanian-Maastrichtian age known from North America. Studies by Frederiksen (1987, 1989) and Frederiksen and Schindler (1987) demonstrate a change in the composition of the microfloral assemblages from the Campanian to the Late Maastrichtian. Overall, the diversity of angiosperms increases from Campanian to Middle Maastrichtian and decreases during the Late Maastrichtian. One hundred ten angiosperm pollen taxa have been identified from Campanian and Maastrichtian rocks (Frederiksen, 1989). Wolfe (1985) describes this as a platanoid flora.

Frederiksen *et al.* (1986) report that the Late Maastrichtian assemblages are substantially reduced in numbers of pollen species: 28 deciduous angiosperm pollen taxa, including only three species of *Proteacidites* (evergreen angiosperms), and eleven gymnosperm taxa. They also note that the Late Maastrichtian rocks contain a large and diverse assemblage of spores of bryophytes and pteridophytes. Wolfe (1985) classifies this entire assemblage as a polar broad-leafed deciduous forest **(Table 15)**.

Frederiksen (1989) considers *Wodehouseia quadrispina* to be a Late Maastrichtian index taxon for northern latitudes. This species is found in Prince Creek assemblages. Other Campanian-Maastrichtian indicators found in the Prince Creek assemblages include one species of *Cranwellia*, two species of *Wodehouseia*, two species of *Azonia*, and one species of *Expressipollis* (Nichols and Sweet, 1993). Frederiksen *et al.* (1986) report abundant species of pteridophytes (ferns), lycophytes (club moss) and bryophytes (mosses) but record only two gymnosperm pollen taxa. Similarly, Spicer and Parrish (1990) and Spicer (1999) identify only six taxa of coniferous wood in the Prince Creek Formation. The low diversity of coniferous gymnosperm pollen species is thus confirmed by the low diversity of conifer wood taxa. Overall, gymnosperm taxa are low in diversity relative to angiosperm taxa (Frederiksen *et al.*, 1987).

Twenty one species of triprojectate pollen, 19 species of oculate pollen **(Tables 29, 30)**, and three species of the *Callistopollenites* Group (Frederiksen *et al.*, 1986) establish the Prince Creek-Colville Group paleofloras as components of the *Aquilapollenites* Province (Nichols and Sweet, 1993). Prince Creek assemblages contain few taxa characteristic of the Continental Margin Province of the central west coast of North America (Frederiksen, 1987).

Frederiksen *et al.*, (1986) suggest that the Arctic assemblages represent a cooler, more arid inland climate. Nevertheless, three species of *Proteacidites* pollen suggest a coastal influence on these Arctic paleofloras (Frederiksen *et al.*, 1987). In summary, the 40 pollen species of the Triprojectate and Oculate Groups in the Prince Creek and Colville Group assemblages, in association with triprojectate pollen grains of the known deciduous angiospermous *Kurtziflora* (McIver *et al.*, 1991) **(Tables 29, 30)** and the limited number of *Proteacidites* pollen species, indicate a cooler, more arid coastal margin.

Significant differences in diversity of *Aquilapollenites* Group taxa are present between southern and northern paleofloras **(Tables 31, 32)**. Nine species of *Mancicorpus* are present in the Matanuska paleoflora compared to four in the Prince Creek flora. The Prince Creek flora contains 12 species of *Wodehouseia* while only four species are present in southcentral Alaska. The Prince Creek flora also contains six pollen species of *Azonia*, but no *Azonia* species have been found in the Matanuska flora. Although floras of the Alaska Peninsula contain six species of *Azonia*, only *A. fabaceae* is shared with the Prince Creek flora. Based on studies by Nichols and Sweet (1993) which

Table 32
Geographically endemic species of triprojectate pollen in Campanian-Maastrichtian rocks of Alaska
red = arctic, green = interior, blue = southcentral, black = widespread

(Tschudy, 1969; Wiggins, 1976, 1988; Mancini *et al.*, 1978; Magoon *et al.*, 1980; Frederiksen, 1989, 1990; Sweet, 1994 a, b)

Species name	Prince Creek Fm.	L. Cantwell Fm.	Matanuska Fm.	Alaska Peninsula
1. *Aquilapollenites* aff. *A. abscisus*	X			
2. *A. alaskensis*	X			
3. *A. amicus*	X			
4. *A. aptus*		X		
5. *A. attenuatus*		X	X	
6. *A.* cf. *augustus*	X		X	
7. *A. bertillonites*			X	
8. *A. caterireticulatus*				X
9. *A. clairireticulatus*		X	X	
10. *A. conatus*	X		X	
11. *A. contiguus*		X	X	
12. *A. delicatus*	X		X	
13. *A. delicatus* var. *delicatus*				X
14. *A. drumhellerensis*		X		
15. *A. fusiformis*	X	X		
16. *A. immiser*	X			
17. *A. notibile*			X	
18. *A. parallelus*		X		X
19. *A. polaris*				X
20. *A. quadrilobus*	X	X	X	X
21. *A. rigidus*		X		
22. *A. rectus*		X		
23. *A. regalis*		X		
24. *A. reticulatus*	X	X	X	
25. *A. scabratus*		X	X	
26. *A. senonicus*	X	X	X	X
27. *A. spinulosus*			X	
28. *A.* sp.	X		X	
29. *A. trialatus*		X	X	
30. *A. turbidus*		X		X
31. *A. unicus*	X			
32. *A. venustrus*		X		
33. *Bratzevaea amurensis*	X			
34. *Fibulapollis inaequalis*	X			
35. *F. mirificus*		X		X
36. *F. scabratus*	X			
37. *Mancicorpus albertensis*			X	
38. *M. anchoriforme*	X			X
39. *M.* sp.			X	
40. *M. borealis*			X	
41. *M. canadiana*			X	
42. *M. delicatus*	X			
43. *M. notabile*	X		X	
44. *M. pseudosenonicus*	X			
45. *M. pulcher*			X	
46. *M. rostratus*	X		X	
47. *M.* cf. *trapeziforme*			X	
48. *M.* cf. *tripodiformis*			X	
Grand totals of endemic species:	**10**	**6**	**10**	**3**

Table 33

Geographically endemic species of oculate pollen in Campanian-Maastrichtian rocks of Alaska

red = arctic, green = interior, blue = southcentral, black = widespread

(Wiggins, 1976, 1988; Mancini *et al.*, 1978; Magoon *et al.*, 1980; Frederiksen, 1989, 1990; Sweet, 1994 a, b)

Species Name	Prince Creek Fm.	L. Cantwell Fm.	Matanuska Fm.	Alaska Peninsula
1. *Azonia cf. hirsuta*	X			
2. *A. cribrata*	X			
3. *A. fabacea*	X	X		X
4. A. hirsuta	X			
5. A. parva		X		X
6. *A. pulchella*	X			
7. *A. recta*				X
8. *A. reticulata*				X
9. *A. rugulos*				X
10. *A. strictiparva*	X			
11. *A. sufflata*		X		X
12. *Wodehouseia asper*	X			
13. *W. avita*				X
14. *W. bella*	X			
15. *W. capillata*			X	X
16. *W. edmontonicola*	X			
17. *W. elegans*	X			
18. *W. fimbrata subsp. constricta*	X			
19. *W. gracile*	X		X	
20. *W. octaspina*	X			
21. *W. quadraspina*	X			
22 *W. spinata*	X			X
23. *W. stanleyi*	X			
24. *W. vestivergata*	X			
25. *W. wigginsii*	X			
Grand totals of endemic species:	**15**	**0**	**1**	**5**

state that

> Latitudinally controlled paleoclimate is presumably the cause of paleofloristic variation within the *Aquilapollenites* Province of North America,

I interpret these differences as responses to regional temperatures and regimes determined by different paleolatitudes.

Distribution of temperate and tropical species in Campanian-Maastrichtian paleofloras of Alaska

The most noticeable difference between the Campanian-Maastrichtian Arctic, interior and southcentral paleofloras is a north-south decrease in the number of oculate species, and accompanied by an increase in the number of triprojectate *Mancicorpus* species **(Tables 31, 32)**. This suggests that oculate species were more successful in a cool, arid arctic climate than in a warm arid or warm humid climate (Wiggins, 1976). In contrast, triprojectate species appear to be more successful in the warmer southcentral regions of Alaska. During the Maastrichtian the climate became cooler and drier, the CWIS regressed and the number of both triprojectate and oculate pollen taxa "dropped dramatically" (Srivastava, 1970) in assemblages in the Edmonton Formation, Alberta, Canada. For example, species

of *Aquilapollenites* dwindled from 45 to 12 at the end of the Cretaceous and finally vanished during the Paleocene (Srivastava, 1970). The diversity of Arctic Alaska oculates, however, suggests they were more robust and therefore able to withstand the drier, cooler Arctic coastal climates of the Late Maastrichtian.

Changes in diversity of two Gondwanan pollen genera associated with warm, humid climates, *Proteacidites* and *Podocarpidites*, support a latitudinally-controlled north-south temperature gradient. *Proteacidites* species increase from three in the Arctic to four in the interior and seven in southcentral Alaska **(Appendix A)**. The numbers of *Podocarpidites* species in the Arctic floras are not recorded. None were reported in the Cantwell Formation, but five species of *Podocarpidites* are present in the Campanian Hicks Creek assemblage and seven species in the Maastrichtian Mazuma Creek assemblage, both of southcentral Alaska. This suggests that a warmer, more humid climate prevailed in southern Alaska throughout the Campanian-Maastrichtian.

Pollen grains of two species of *Platysaccus*, the seed fern genus, were found in the Matanuska Formation, but this genus is not reported in either the Prince Creek or the Cantwell Paleofloras. Seed ferns are Gondwanan elements

typically associated with tropical and subtropical climates (Traverse, 1988), and their presence in the Matanuska Formation is further evidence for a relatively warm and wet climate in southcentral Alaska.

Geographically endemic pollen species found in the Campanian-Maastrichtian paleofloras of Alaska

Geographically endemic, or regionally restricted (Nichols and Sweet, 1993), species of triprojectates and oculates are recognized in the Prince Creek, Cantwell, Matanuska and Alaska Peninsula paleomicrofloras **(Tables 32, 33)**. The Prince Creek assemblages contain 10 triprojectate and 15 oculate pollen species endemic to the Arctic Alaska region; the Lower Cantwell assemblages contain six endemic triprojectate species; and the Matanuska, Chignik and Kaguyak Formations contain 13 endemic triprojectate and five endemic oculate species **(Tables 32, 33, 34)**. These species probably represent adaptations to regional climate regimes.

Interpretations of regional paleoclimates

Frederiksen (1987) characterized the Continental Margin Province as tropical based on the abundance of fern spores and of *Proteacidites* Group pollen, the scarcity of

Table 34

A summary of the geographically endemic pollen assemblages of the Prince Creek Formation, the Lower Cantwell Formation, and the combined Matanuska and Alaska Peninsula assemblages (Tables 27, 28)

Prince Creek endemic pollen assemblage

10 Triprojectate species
15 Oculate species
Total: 25

Lower Cantwell endemic pollen assemblage

Total: 6 Triprojectate species

Matanuska and Alaska Peninsula pollen assemblage

13 Triprojectate species
5 Oculate species
Total: 18

Normapolles species, and the absence of *Aquilapollenites* Group and *Callistopollenites* Group pollen.

Frederiksen (1987) associated species of the *Aquilapollenites* Group with arid interior climates of the late Campanian San Juan Basin in the southwest United States east of the Rocky Mountains. He also noted that *Kurtzipites* was a prominent element of that arid inland microflora. In their description of the deciduous plant *Kurtziflora antherosa*, McIver *et al.*, (1991) assert that its deciduous character extends to the entire *Aquilapollenites* Group. Support for this theory is provided by the association of *Kurtziflora antherosa* with *Aquilapollenites* pollen types

throughout the mid regions of the North American *Aquilapollenites* Province, primarily Alberta, Saskatchewan and Manitoba, but also the North West Territories and Yukon Territory, Canada (McIver *et al.*, 1991). The implication is that the plants which produced the pollen of the *Aquilapollenites* and the *Callistopollenites* Groups were probably small, herbaceous, deciduous plants similar to *Kurtziflora antherosa*. These plants were successful in seasonally cool or arid (stressful) environments (Axelrod, 1966; Wolfe, 1987).

Prince Creek Formation. The Prince Creek paleomicroflora contains an abundance of pollen species from the *Aquilapollenites* and *Callistopollenites* Groups **(Table 29, 30)**. These pollen types are from angiosperm plants which now can be considered to be deciduous (McIver *et al.*, 1991) **(Table 9)**. The deciduous character of the Arctic Alaska flora is supported by recovery of deciduous, serrated platanoid leaves (Spicer *et al.*, 1987), wood with high ratios of early to late wood (Spicer and Parrish, 1990), and the discovery of vining cycads (Spicer and Hermann, 1996) discussed in Chapter 2.

Direct association of the *Aquilapollenites* and *Callistopollenites* pollen groups with arid environments in

other regional settings (Frederiksen *et al.*, 1987) suggests that the deciduous character of the Prince Creek paleoflora may be an adaptation to an arid environment. Ultimately, the palynological evidence lends support to a cool, temperate, and perhaps much more arid climate in Arctic Alaska during the Campanian-Maastrichtian than has previously been suspected.

Tropical type angiosperm pollen species, including *Proteacidites, Arecipites* and TCT gymnosperm pollen, are a rarity in the Late Maastrichtian Prince Creek paleoflora (Frederiksen *et al.*, 1987). This sparseness further supports a cool, temperate climate reconstruction.

Lower Cantwell Formation. Compared to the Campanian-Maastrichtian Prince Creek paleoflora, the Lower Cantwell paleoflora has more TCT species, 55 percent fewer species of the *Aquilapollenites* Group **(Tables 29, 30)**, and only one species of *Kurtzipites* pollen. The decrease in species of a genus associated with arid environments, *Aquilapollenites*, suggests that the Late Cretaceous Cantwell Basin paleoclimate may have been more humid than the Prince Creek paleoclimate. However, the absence of *Proteacidities* and the presence of an intermediate number of *Aquilapollenites* Group species may indicate that moderately arid conditions

persisted in the interior basin relative to the southern margin.

Matanuska Formation. Crickmay and Pocock (1963) considered *Beaupreadites*, specifically *Beaupreadites elegansiformis* Cookson, and spores of the genus *Appendicisporites* characteristic of the Continental Margin Province. Both genera are present in the Matanuska paleoflora **(Table 31)**.

Two of the TCT pollen genera, *Metasequoia* and *Podocarpus* **(Table 21)**, recovered from the Mazuma Creek assemblages represent gymnosperm trees known to have lived in warm swampy environments, implying a subtropical to tropical climate (Taylor and Taylor, 1993) for the Matanuska paleoflora. Three species of *Cedrus* are also present and support a subtropical climate (Miki, 1977).

Trilete/Monolete (T/M) spores from the Mazuma Creek assemblages include several species of seed ferns and 84 species of fern and tree fern spores **(Table 15)**. These assemblages further suggest that a subtropical to tropical macroflora dominated the nonmarine environment of the Talkeetna island arc in southcentral Alaska during the Late Maastrichtian **(Appendix A)**.

An additional factor to consider in the ecological interpretation is the recurring volcanic events, recorded by numerous ash deposits in the outcrops at Mazuma Creek. The volcanic ash deposits must have modified the flora of the island arc system. Three separate ash layers and a volcanic bomb were identified in the Mazuma Creek outcrop **(Fig. 37)**, and trilete spores are the dominant palynomorphs in the assemblages above these sample sites **(Table 15)**. Thus, trilete spore diversity of the Matanuska Paleoflora may be a result of repeated local volcanism rather than a response to temperature or humidity gradients.

Yukon-Tanana basin paleofloras

Deposits of Maastrichtian age pollen from Chicken and Eagle, of the Yukon-Tanana Terrane in eastern interior Alaska, contain low-diversity fossil pollen assemblages dominated by *Aquilapollenites*. These low-diversity assemblages also include *Cranwellia* (Tschudy, 1969; Foster and Igarashi, 1989), characteristic of the *Aquilapollenites* Province, and some TCT pollen. Pollen and spore taxa associated with the Continental Margin province, such as *Arecipites*, *Proteacidites*, *Podocarpidites*, and

Appendicisporites are not reported from this region, although spores of *Cicatricosisporites* are.

Although paleolatitude data are not included in those reports, the dominantly triprojectate microflora in these assemblages suggest that eastern interior Alaska paleoclimates may have been arid, similar to the cool, arid climate of the Cretaceous North Slope (Spicer and Parrish, 1986; Parrish and Spicer, 1988; Frederiksen, 1989), or warm and arid, similar to the San Juan basin of southwest North America (Frederiksen, 1987), or similar to the arid climate of the western margins of the CWIS (Wolfe and Upchurch, 1987). Overall, these assemblages are most similar to the paleomicroflora of the Lower Cantwell Formation, implying a relatively warm, dry climate.

Comparison of the Matanuska paleoflora to floras along the North Pacific Rim

Alaska Peninsula. The Chignik and Kaguyak Formations on the Alaska Peninsula (Wiggins, 1976; Mancini *et al.*, 1978; Magoon *et al.*, 1980) contain pollen taxa similar to those in the Matanuska Formation, suggesting a coastal ecosystem. Eight triprojectate pollen species and nine species of oculate pollen were recognized by Greisbach (*in* Mancini *et al.*, 1978) and by Wiggins (1976). Compared to

the Arctic Alaska assemblages, therefore, the Alaska Peninsula floras contain fewer triprojectate and oculate taxa, indicating a moderately humid climate. Hollick (1930) cited the presence of a cycad species in the Chignik macroflora which, it is remarkable to note, Kryshtofovich identified in 1918 on the Russian island, Sakhalin (northwest of Japan), as a "coastal cycad." Thus, I conclude that the Chignik and Kaguyak microfloras represent coastal ecosystems.

Western North Pacific Rim. In the northwestern region of the Pacific Rim, the Navarin Basin contains pollen taxa characteristic of the cool, dry, interior *Aquilapollenites* Province. The Hakobuchi paleoflora is more similar to the Prince Creek Paleoflora in that it contains two Proteaceous pollen species in addition to diverse triprojectate taxa. The Bureya paleoflora is similar to the Matanuska paleoflora, with characteristic elements of both the Continental Margin Province and the *Aquilapollenites* Province.

Comparison of western North Pacific Rim paleofloras to the Matanuska paleoflora

Paleofloras of Frederiksen's (1987) Continental Margin Province are taxonomically and compositionally similar to

Table 35

Comparison of the important microfloral (x) and macrofloral (X) elements present in the North Pacific Rim paleofloras with the Alaska paleofloras
(Kryshtofovich, 1918; Hollick, 1930; Miki, 1941, 1977; Bell, 1957; Samoilovich, 1967; Wiggins, 1976, 1988; Mancini *et al.*, 1978; Magoon *et al.*, 1980; Turner *et al.*, 1985; Frederiksen, 1987, 1989, 1990; Foster and Igarashi, 1989; Sweet, 1994a, 1994b; Ridgway *et al.*, 1997)

NORTH PACIFIC RIM PALEOFLORAS

	Matanuska	Chignik	Kaguyak	Nanaimo	La Panza	Bureya	Sakhalin Basin	Northern Japan	Primorsk	Navarin Basin	Prince Creek	Cantwell	Chicken/Eagle
ARID CLIMATE													
TCT	x	(X)				x		(X)			x	x	x
Triprojectates	x	x	x			x		x	x	x	x	x	x
WET CLIMATE													
Proteacidites	x	x	x	x	x	x		x			x		
Podocarpus	x							x					
Coastal Cycad *(Nilssonia serotina)*		(X)		(X)			(X)						
Ferns	x	x		x	x	x		x			x	x	

the paleofloras of the Bureya region of Eastern Siberia **(Table 35)**. The Bureya paleofloral assemblages include the "constant presence of pollen of the tropical and subtropical families of the Proteaceae" in association with Taxodiaceae pollen (Samoilovich, 1967) and *Cedrus* pollen (Miki, 1997). Late Cretaceous floras of Bureya are similar

to those of the Upper Hakobuchi Group of Northern Japan with respect to fern spore diversity (Miki, 1977). However, the Hakobuchi Group assemblages also contain 24 species of *Aquilapollenites*, two species of *Wodehouseia*, two species of *Proteacidites* pollen, one genus of *Podocarpidites*, but lack *Azonia* or *Cedrus* pollen (Miki, 1977). The Hakobuchi Group paleoflora is thus more similar to the Arctic Alaska floras than either the interior or southcentral Alaska floras **(Table 35)**.

The Navarin Basin paleoflora, recovered from a basin on the Bering Sea Shelf (**Figs. 11, 12)** was extracted from conglomerates and coal deposits very similar to the nonmarine units in the Matanuska Formation. This small assemblage contains several triprojectate pollen taxa, but no fern species or Gondwanan taxa are recorded. The Navarin paleoflora was probably derived from the Russian Far East and transported south and east to the Navarin Basin (Turner *et al.*, 1985). Turner *et al.*, (1985) suggest that the paleoclimate was warm temperate, "possibly subtropical", based on the pollen assemblage. Paleomagnetic studies of drill core from Navarin Basin COST Well No. 1 show that the Late Cretaceous rocks underlying the Navarin Basin formed at a paleolatitude of 31° N $\pm$2° (Van Alstine and Whitney, 1984)

and traveled northward at a rate >100 mm/yr between the Campanian and Eocene.

Implications for a continuous continental margin paleoflora from the Russian Far East to California

Campanian-Maastrichtian paleomicrofloral assemblages of the Russian Far East and southcentral Alaska resemble the continental margin paleomicrofloras of western Canada, Washington and California. Common denominators are the diversity of *Proteacidites* pollen and trilete (fern) spores and low diversity of *Aquilapollenites* Group pollen. These are the defining characteristics of Frederiksen's (1987) Continental Margin Province.

However, Campanian-Maastrichtian Matanuska Formation paleofloral assemblages from the Mazuma Creek, Syncline Mountain, Slide Mountain and Granite Creek sites are more diverse than the floras of the Continental Margin Province. Of the Pacific Rim floras, the Matanuska assemblages contain the largest numbers of *Aquilapollenites* and Proteaceae group species along with an abundance of fern, moss, and club moss spores. Although the Matanuska paleoflora contains two genera of Proteaceous pollen, the Proteaceae Group is more diverse in the Nanaimo and La Panza continental margin paleofloras.

In that the Matanuska Paleoflora contains taxa characteristic of the Continental Margin Province, it is typical of the floras of the North Pacific Rim. However, it also contains abundant species of the *Aquilapollenites* Group characteristic of the *Aquilapollenites* Province. Therefore, I interpret the Matanuska assemblage to represent the intersection of both floral provinces. Furthermore, the Matanuska paleoflora must be located along a coastal dispersal corridor, because it is more diverse than any of the other north Pacific Rim paleofloras reviewed in this study. This diversity is interpreted as the result of the mixing of Continental Margin Province plant species with northern *Aquilapollenites* Province plant species along the Pacific Rim.

Interpretations of paleolatitudes and age

Reconstructed paleolatitudes of <75° N presented herein for the Matanuska Formation and the Lower Cantwell Formation north of the Talkeetna Mountains **(Table 20)** correspond generally with a Maastrichtian paleolatitude of 71° N ±10° derived from geophysical data (Panuska and Macicak, 1986). Panuska and Stone (1985) place the Eocene Talkeetna mountains at 80° N ±9° based on data from the Cantwell volcanics, while Hillhouse *et al.* (1985) place the

Peninsular Terrane at 76° N ±10° during the Eocene based on paleomagnetic remnant data extracted from volcanics in the northern Talkeetna Mountains. These three paleomagnetic reconstructions suggest that the Late Maastrichtian Matanuska Formation was probably positioned between 70°-75° N. The palynological data presented herein are thus in general agreement with paleomagnetic reconstructions of paleolatitude.

Summary of the Late Cretaceous floras of Alaska

At the Mazuma Creek site, the Matanuska Paleoflora consists of 75 genera of T/M spores which represent ferns, tree ferns, bryophytes, lycophytes and sphenophytes (**Table 36**). These species are inhabitants of mixed forests, floodplains, streamsides, and shorelines. An abundance of *Steriosporites* (sphagnum moss) and *Lycopodium* (club moss) suggest damp, perhaps swampy environments along island coastlines. Three spore genera recovered from the Slide Mountain assemblage represent very swampy environments: *Aequitriradites spinulosus*, a hepatica spore; *Ceratosporites*, the spore of a water fern genus; and species of the fern genus *Gleicheniidites*. This assemblage is indicative of a coastal mixed forest of hardwoods and

Table 36
Partial list of plant families represented, derived from spore and pollen data
(modified from Erdtman, 1943; Tschudy and Scott, 1969; Traverse, 1988)

BRYOPHYTA (true mosses, liverworts)
- *Stereiosporites antiquasporites*
- *Aequitriradietes* sp.

LYCOPHYTA (club moss, spike moss)
- *Lycopodiumsporites* sp.
- *Neoraistrickia* sp.
- *Selaginella* sp.

SPHENOPHYTA (horsetails)
- *Calamospora* sp.
- *Laevigatosporites* spp.

PTERIDOPHYTA

Filicales (true ferns)

Dicksoniaceae
- *Cyathidites* spp.

Gleicheniaceae
- *Concavisporites* sp.
- *Concavissimisporites* sp.
- *Deltoidospora* spp.
- *Gleicheniidites* spp.

Matoniaceae
- *Dictyophyllidites* spp.
- *Matonisporites* sp.

Osmundaceae
- *Osmundacites* spp.
- *Todisporites* spp.

Polypodiaceae
- *Baculatisporites* spp.
- *Polypodiiates* spp.

PTERIDOPHYTA (cont'd)

Schiazeaceae
- *Anemia* sp.
- *Appendicisporites* spp.

Marattiales (tree ferns)
- *Laevigatosporites* spp. (*Psaronius* tree)

PTERIDOSPERMOPHYTA (seed ferns)
- *Alisporites grandis* - *Dicroidium*
- *Pityosporites* spp.
- *Platysaccus* spp. - *Dicroidium*
- *Vitreisporites* spp.

conifers with an understory densely populated by ferns, and edged by coastal swamps. Rare bryophyte and sphenophyte spores suggest proximity to coastal swamps.

Well-preserved pollen grains of the herbaceous Liliaceae and a small number of seed fern and cycad grains all represent plants which formed mid-to-lower canopy elements. Pollen of upper canopy conifers includes *Metasequoia* (dawn redwood), *Taxodium* (bald cypress), *Pinus* (pine), *Picea* (spruce), *Podocarpus* (Gondwanan conifers), *Cedrus* (cedar), and *Ginkgo*, a broadleaf deciduous gymnosperm. Hardwood angiosperm trees and shrubs are represented by two species of *Nyssapollenites* pollen and one species of *Nyssoidites* (sour gum), cf. *Quercus* (oak), *Proteacidites* (trees or intermediate shrubs), *Ilex* (holly), *Ulmoideipites* and *Momipites* (elms). These plants probably formed a secondary canopy **(Table 37)**.

Preservation of pollen and spores in the assemblages is not equal. Angiosperm triprojectate and oculate pollen grains tend to be more battered and corroded than trilete spores. Although diverse angiosperms are present, each species is represented by only a few grains. Their poor physical condition suggests that these flowering trees and herbs lived in the uplands some distance from the depositional basin. However, gymnosperm pollen, including

Table 37
Partial list of plant families represented, derived from spore and pollen data
(modified from Erdtman, 1943; Tschudy and Scott, 1969; Traverse, 1988)

GYMOSPERMOPHYTA
- **Non-conifers**
  - *Ephedrapites* sp.
  - *Ginkgo* - tree
- **Conifers**
  - *Cedripites* spp.- cedar trees
  - *Eucommiidites* spp. - conifers
- **Pinaceae**
  - *Parvisaccites* sp. - pine trees
  - *Piceapollenites* spp. - spruce trees
  - *Pinuspollenites* spp. - pine trees
  - *Rugubivesiculites* spp. - conifers
- **Podocarpaceae**
  - *Podocarpidites* spp. - conifers
- **Taxodiaceae-Cupressaceae-Taxaceae**
  - *Taxodiaceaepollenites hiatus* - Metasequoia trees
  - *T. vacuipites* - Metasequoia trees
  - *Sequoia* sp.

ANGIOSPERMOPHYTA
- **Monocotyledonae**
  - **Liliaceae**
    - *Liliacidites* sp. - lily
- **Dicotyledonae**
  - **Betulaceae**
    - *Alnipollenites* spp. - alders
  - **Olacaceae**
    - *Anacolosidites* spp. - flowering shrubs, trees, vines
  - **Aquifoliaceae**
    - *Ilexopollenites obscuricostata* sp. - holly shrub
  - **Proteaceae**
    - *Proteacidites* spp. - flowering shrubs, trees
  - **Fagaceae**
    - cf. *Quercus explanata* - oak tree
  - **Myricaceae**
    - *Myrica* sp. - shrub
  - **Tiliaceae**
    - *Tilia wodehousei* - linden (lime) tree
  - **Ulmaceae**
    - *Momipites* sp.
    - *Ulmoideipites herbridicus* - elm tree

Metasequoia, *Sequoia*, bald cypress, *Ginkgo*, and cycads, are abundant and in good condition, suggesting that they lived closer to the basin.

Cornutisporites seebergensis Schultz and *Triancoraesporites reticulatus*, Triassic trilete spores restricted to the Rhaetian (Tschudy and Scott, 1969), were recovered in Florule D-6 of the Mazuma Creek study site **(Table 22)**. *T. reticulatus* was also found at sample site F, in the marine onlap sequence **(Appendix A)**. All three grains are well preserved. This suggests that either the grains were from plants that were living at the time the Matanuska Formation was being deposited, or that the spores were not transported long distances after eroding from Triassic deposits. These spores have not been previously recognized in Cretaceous deposits. The two nearest Upper Triassic units in the southcentral region are the Kamishak Formation and the Wrangellia Terrane. The Kamishak Formation located at Puale Bay (Sralla and Blodgett, 2007) approximately midway between Chignik and Saddle Mountain on the eastern side of the Alaska Peninsula, is approximately 700 km (438 miles) southwest of the Talkeetna Mountains. The Wrangellia Terrane, which is Late Triassic to Jurassic age (Plafker *et al.*, 1994), is approximately 250 km (155 miles) to the east of the Talkeetna Island Arc system. Therefore the possible

source of the Rhaetian age spores is more likely to have been from an Uppermost Triassic unit within the Wrangellia Terrane.

When the five study sites are evaluated as a group, the Matanuska paleoflora includes a large number of fern species, abundant gymnosperm pollen grains of the TCT group, and pollen of several seed ferns, including *Dicroidium* (Traverse, 1988). Several species of *Cedrus* (cedar) are also present. Twenty-four triprojectate and two oculate form species, two species of *Cranwellia,* and one species each *Callistopollenites* and *Erdtmanipolles* (*Callistopollenites* Group) are present. A total of seven genera of *Proteaceae* pollen (broad leaved evergreen angiosperms) and two genera of *Normapolles* pollen are represented.

The scarcity, low diversity and poor preservation of pollen species of the *Aquilapollenites* Group reflect transport from a relatively distant inland site. Pollen species of the *Callistopollenites* Group are neither abundant nor diverse at any of the Matanuska Formation sites, which suggests that these palynomorphs are probably also from inland sites.

The Slide Mountain and the Mazuma Creek assemblages contain seven species of *Proteacidities* pollen, elements

typical of the Late Cretaceous tropical rainforests of Gondwana (White, 1990). Five species of *Podocarpidites* pollen have been found in the Hicks Creek assemblage, 12 in the Mazuma Creek assemblages and three in the Slide Mountain assemblage. The presence of *Podocarpidites* pollen, another Gondwanan gymnosperm element, strongly suggests a warm tropical climate (Douglas and Williams, 1982). These characteristics invite comparison with Frederiksen's (1987) Continental Margin Province.

Overall, differences in composition between paleofloras of the Prince Creek, Lower Cantwell, and Matanuska Formations point to three distinct paleoenvironments located in northern, interior and southcentral Alaska during the Campanian and Maastrichtian. The Late Cretaceous paleofloras of Arctic Alaska lived in the foothills and coastal plains under temperate to cool-temperate climate conditions, as indicated by the overwhelmingly deciduous character of that flora (Spicer, 1987). Aridity is indicated by abundant presence of pollen taxa belonging to the *Aquilapollenites* and *Callistopollenites* Groups (Frederiksen, 1987; McIver *et al.*, 1991).

As represented by the paleomicroflora of the Cantwell Formation, the climate of interior Alaska seems to have been moderately humid and warmer than that of Arctic Alaska.

This milder climate is indicated by a 55 percent reduction in species of the *Aquilapollenites* Group. No *Proteacidites* genera are present, which suggests that the Cantwell flora is an inland flora. Sweet (1994a, 1994b) found an abundance of TCT and *Ginkgo* pollen in one horizon of the Lower Cantwell Formation which provides support for a relatively warm, humid environment (Srivastava, 1970).

The Matanuska Paleoflora of southcentral Alaska is more diverse. The combination of palynomorphs indicative of a tropical to subtropical climate with diverse fern spores and pollen species of the *Aquilapollenites* and *Callistopollenites* Groups is best explained as the intersection of two floral provinces.

Samoilovich (1967), Frederiksen (1987), and Spicer (1987) all considered land barriers to be important factors in the development of regional paleofloral populations and, ultimately, paleofloral assemblages. The proto-Alaska Range and the Brooks Range are thus significant to the development of regional Alaskan floras during the Cretaceous. These land barriers influenced the climates and ecosystems of interior Alaska by limiting the amount of precipitation and restricting the migration of plant species.

Recommendations for further studies

Wood cells are abundant in several palynomorph assemblages recovered from the Matanuska Formation. Only six specimens of the wood are tentatively identified; others may represent plant species not found in the palynomorph assemblages. Further study of wood specimens would increase understanding of the Late Maastrichtian vegetation and climate of southcentral Alaska.

Fungal spores found in the Matanuska Formation have not been systematically studied. Nearly all the fungal spores I found were in conjunction with shell hash and ammonite fossils in concretions. Because these concretions were not found *in situ*, I did not include them in this report. However, a better understanding of micro-environments may be gleaned from a study of these materials.

Additional evaluation of volcanic recovery floras would also be useful as radiometric dating of individual ash beds may be possible. Radiometric dating would provide a test of the ages assigned herein. The pace of recovery of the Matanuska flora and the length of the disturbance intervals may also be determined.

Summary and Conclusions

The Matanuska Formation paleoflora contains taxa characteristics of both the *Aquilapollenites* and Continental Margin Provinces. Triprojectate and Oculata Groups taxa are characteristic of the *Aquilapollenites* Province; abundant fern spore genera and nine of 16 pollen genera are characteristic of the Continental Margin Province. Thus, the Matanuska Formation paleoflora 1.) contains a mixture of palynomorphs from both the *Aquilapollenites* and Continental Margin Provinces; 2.) represents the intersection of the *Aquilapollenites* Province and Continental Margin Province; and 3.) comprises a unique transitional continental margin flora positioned between the western and eastern North Pacific Rim. The presence of *Proteacidities and Beaupreadites* pollen in association with abundant species of trilete spores is characteristic of the Continental Margin Province. Despite differences in species composition, overall assemblage composition suggests a continental margin flora that extends from the Bureya region of the Russian Far East, across southcentral Alaska to the Nanaimo and La Panza regions on the western coast of North America.

Distinct regional pollen assemblages can be recognized within the northern, central and southcentral regions of Alaska during the Campanian and Maastrichtian Stages. These

regional assemblages represent distinct paleoclimates. Paleoclimate reconstructions are based on 4 criteria:

1.) Frederiksen's (1987) association of *Aquilapollenites* with warm arid environments;

2.) The deciduous nature of the fossil plant *Kurtziflora antherosa* (McIver *et al.*, 1991) which produces the triprojectate *Kurtzipites trispissatus* pollen. This strongly suggests that associated triprojectate and oculate pollen forms were derived from deciduous, herbaceous plants capable of withstanding environmental stress such as seasonality or aridity;

3.) An increase in diversity of triprojectate pollen and a decrease in oculate pollen diversity from north to south. The northern flora is composed of *Aquilapollenites* and *Wodehouseia* taxa specific to Arctic Alaska, the interior flora includes *Aquilapollenites* and *Azonia* taxa specific to interior Alaska, and a third southcentral Alaska flora contains species of *Aquilapollenites* and *Wodehouseia* not found in the central and northern Alaska floras. This latitudinal diversity and composition gradient suggests that flora composition was influenced by paleoclimate.

4.) An increase in floral elements with humid tropical Gondwanan affinities from north to south.

These four factors suggest regional paleoclimate differences: warmer and more humid to the south, warm and dry in the interior, and cool and dry to the north.

The pollen taxa *Tricolpites microreticulatus*, *Tilia* sp. cf. *T. wodehousei* and *Mancicorpus rostratus* indicate that the Matanuska Formation was deposited during the Late Maastrichtian at latitudes <75° N. Paleolatitude reconstructions based on endemic pollen taxa suggest that the Matanuska Formation generally corresponds with paleolatitudes of 71^0 N $\pm 10°$ derived from paleomagnetic data (Panuska and Macicak, 1986). The Lower Cantwell Formation was deposited between 60°-75° N. Pollen taxa from the Arctic Alaska Prince Creek Formation indicate paleolatitudes >75° N.

Repeated volcanic eruptions had a destructive effect on the Matanuska Formation paleoflora. Each recovery of the flora began with a return of ferns, followed by a low diversity, "weedy" vegetation. Finally, a mixed gymnosperm-angiosperm forest re-established growth.

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APPENDIX A

Locator numbers

All photographs of pollen and spore grains were enlarged by 1000x magnification using a 100x oil immersion lens with 10x objectives.

Each palynomorph photograph has 1.) a film roll number and a photographic sequence code (for example, R9-25 means Roll 9, photograph 25); 2.) a directional arrow (either ↑ or ↓), and 3.) alpha-numeric locators (for example, 5T).

The alpha number locator numbers can be used to relocate pollen grains on the study slides. At the beginning of study a slide was placed right side up on the microscope table, with the slide label to the left side. After a palynomorph was photographed, a Lovins Micro-Slide field finder with alpha-numeric coordinates on a grid system was positioned over the site, and the coordinates were noted.

The arrow after each photograph number indicates whether the Lovins field finder grid symbols were in upright (↑) or reverse (↓) position when read.

Scale bars on all plates represent a length of 25 microns (μm).

Table 38

List of slides evaluated for study
Unmarked - processed by ARCO
* - processed by Global GeoLabs

Appendix A

Mazuma Creek - Collection Site A

1. 94SR (MZ) A001*
2. 94SR (MZ) A002*
3. 94SR (MZ) A003*
4. 94SR (MZ) A004*
5. 94SR (MZ) A005*

Appendix B

Mazuma Creek - Collection Site B

6. 94SR (MZ) B001-a*
7. 94SR (MZ) B001-b*
8. 94SR (MZ) B002*
9. 94SR (MZ) B003*
10. 94SR (MZ) B004*
11. 94SR (MZ) B005*

Appendix C

Mazuma Creek - Collection Site C

12. 94SR (MZ) C001*
13. 94SR (MZ) C002*
14. 94SR (MZ) C003*
15. 94SR (MZ) C004*
16. 94SR (MZ) C005*

Appendix D

Mazuma Creek - Collection Site D

17. 94SR (MZ) D001(1)
18. 94SR (MZ) D001(2)
19. 94SR (MZ) D004(1)
20. 94SR (MZ) D006 (1)
21. 94SR (MZ) D006 (2)
22. 94SR (MZ) D0012 (1)
23. 94SR (MZ) D0012 (2)
24. 94SR (MZ) D0013 (1)
25. 94SR (MZ) D0013 (2)

Table 38 continued

Appendix E

Mazuma Creek - Collection Site E

26. 94SR (MZ) E003*
27. 94SR (MZ) E006*

Appendix F

Mazuma Creek - Collection Site F

28. 94SR (MZ) F001*
29. 94SR (MZ) F002*
30. 94SR (MZ) F003*
31. 94SR (MZ) F004*
32. 94SR (MZ) F005*

Appendix G

Syncline Mountain - Collection Sites G

33. 96SR 001-1 (39-1)
34. 96SR 001-2 (39-2)
35. 96SR 002-1 (40-1)
36. 96SR 002-2 (40-2)

Appendix H

Hicks Creek - Collection Sites H

37. 96SR HCK 001-1 (37-1)
38. 96SR HCK 001-2 (37-2)
39. 96SR HCK 002-1 (38-1)

Appendix I

Slide Mountain - Collection Sites I

40. 94SR SM04-1 (18-1)
41. 94SR SM04-2 (18-2)
42. 94SR SM06-1 (19-1)
43. 94SR SM06-2 (19-2)
44. 94SR SM07-1 (20-1)

Appendix J

Granite Creek - Collection Sites J

45. SR93 GrCK 002 (2)
46. SR93 GrCK 004 (1)
47. SR93 GrCK 004 (2)
48. SR93 GrCK 005 (1)
49. SR93 GrCK 005 (2)
50. SR93 GrCK 006 (1)
51. SR93 GrCK 006 (2)

Table 39

Total listing of palynomorphs collected from Mazuma Creek (A-F), Syncline Mountain ((G), Hicks Creek (H), Slide Mountain (I), and Granite Creek (J)

	FUNGAL SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
1	*Colligerites*	*kutchensis*	X				
2	*Dyadosporites*	*substrangulatus*	X				
3	*Fusiformisporites*	*rugosus*	X				
4	*Palambages*	*canadiana*	X				
5	*Pluricellaesporites*	*magnus*	X				
6	*Pluricellaesporites*	*sheffyi*	X				
7	*Tetraporina*	sp.	X				

	WOOD CELLS	A-F	G	H	I	J
1	cf. *Araucarioxylon*	X				
2	cf. *Ginkgo*	X				
3	cf. *Pinus*	X				
4	cf. *Podocarpus*	X				
5	cf. *Sequoia*	X			X	
6	cf. *Taxodium*	X				
7	Unidentified Wood	X		X	X	

	SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
1	*Acanthotriletes*	*varispinosus*	X				
2	cf. *Anemia*	*paradoxa*	X				
3	*Appendicisporites*	*bilateralis*	X				
4	*A.*	sp.	X				
5	*Aequitriradites*	*spinulosus*	X			X	
6	*Baculatisporites*	*comaumensis*	X				
7	*B.*	spp.	X				
9	*Biretisporites*	*potoniaei*	X				
10	*B.*	*psilatus*	X				
11	*B.*	cf. *potoniaei*	X				
12	*Brevimonosulcites*	*corrugatus*	X				

Table 39 continued

	SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
13	*Calamospora*	sp.	X				
14	*Camarozonosporites*	*ambigens*	X				
15	*C.*	*australiensis*	X				
16	*C.*	*insignis*	X				
17	*C.*	sp.	X				
18	*Ceratosporites*	*equalis*	X				
19	*C.*	*levidensis*	X				
20	*C.*	cf. *couliensis*	X			X	
21	*Cibotiumspora*	*juncta*	X			X	
22	*C.*	*jurienensis*	X				
23	*Cicatricosisporites*	*augustus*	X				
24	*C.*	*annulatus*	X				
25	*C.*	*hallei*	X				
26	*C.*	*hughesi*	X				
27	*C.*	*imbricatus*	X				
28	*C.*	*ornatus*	X				
29	*C.*	*pseudotripartitus*	X				
30	*C.*	*radiatus*	X				
31	*C.*	spp.	X				
32	*C.*	cf. *annulatus*	X				
33	*C.*	cf. *hallei*	X				
34	*C.*	cf. *imbricatus*	X				
35	*Cingulatisporites*	*reticingulus*	X				
36	*Cingutriletes*	*clavus*	X				
37	*C.*	sp.	X				
38	*Conbaculatisporites*	sp.	X				
39	*Concavisporites*	sp.	X				
40	*Concavissimisporites*	*punctatus*			X		
41	*Concavissimisporites*	cf. *minor*	X				
42	*C.*	spp.	X			X	
43	*Concavitriletes*	*mesozoicus*	X				
44	*Contignisporites*	sp.				X	
45	*Converrucosporites*	sp.	X				
46	*Converrucosisporites*	cf. *cameronii*	X				
47	*Cornutisporites*	*seebergensis*	X				
48	*Cyathidites*	*australis*	X				
49	*C.*	*diaphana*	X				
50	*C.*	*minor*	X				

Table 39 continued

	SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
51	*C.*	spp.	X				
52	*Deltoidospora*	*diaphana*				X	
53	*D.*	*hallii*	X			X	
54	*D.*	*juncta*	X				
55	*D.*	*neddeni*	X				
56	*D.*	*psilostoma*	X				
57	*D.*	spp.	X		X	X	
58	cf. *D.*	*psilostoma*				X	
59	*Dictyophyllidites*	*harrisii*				X	
60	*D.*	*mortonii*	X			X	
61	*D.*	sp.	X				
62	*Distaltriangulisporites*	*maximus*				X	
63	*Distaltriangulisporites*	*mutabilis*	X				
64	*D.*	*perplexus*	X			X	
65	cf. *Duplosporis*	*ocliferius*	X				
66	*Echinatisporis*	*solaris*	X				
67	*E.*	spp.	X				
68	*Echinosporis*	sp.	X				
69	*Foraminisporis*	*simiscalaris*	X				
70	*F.*	*undulatus*	X				
71	*F.*	*wonthaggiensis*	X				
72	*Foveasporis*	*linearis*	X				
73	*F.*	cf. *linearis*	X				
74	*Foveogleicheniidites*	*confossus*	X				
75	*Foveosporites*	*crassus*	X				
76	*F.*	*subtriangularis*	X				
77	*F.*	Spp.	X				
78	*Foveotriletes*	*palaequestrus*	X				
79	*Gemmatriletes*	*morulus*	X				
80	*Gleicheniidites*	*circinidites*	X		X	X	
81	*G.*	*concavisporites*	X				
82	*G.*	*delicatus*	X				
83	*G.*	*senonicus*	X				
84	*G.*	*umbonatus*	X			X	
85	*G.*	cf. *circinidites*			X		
86	*G*	cf. *senonicus*	X				
87	*G.*	spp.	X			X	

Table 39 continued

	SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
88	*Hamulatisporis*	*amplus*	X			X	
89	*Hazaria*	*canadiana*	X				
90	*H.*	*sheoparii*				X	
91	*Hymenoreticulisporites*	*castallatus*	X				
92	*Interulobites*	*intraverrucatus*	X				
93	*Klukisporites*	*pseudoreticulatus*	X				
94	*Krauselisporites*	*hastilobatus*	X				
95	*K.*	*reissingerii*	X				
96	*Laevigatosporites*	*gracilis*	X				
97	*L.*	*ovatus*	X				
98	*L.*	spp.	X		X	X	
99	*Leptolepidites*	*crepitus*	X			X	
100	*L.*	*proxigranulatus*				X	
101	*L.*	*verrucatus*	X			X	
102	*Lycopodiacidites*	*canaliculatus*	X				
103	*L.*	*caperatus*	X				
104	*L.*	sp.	X				
105	*Lycopodiumsporites*	*crassatus*	X				
106	*L.*	*crassimacerius*	X				
107	*L.*	*marginatus*	X				
108	*L.*	*singhii*	X				
109	*L.*	spp.	X				
110	*Lygodium*	sp.	X				
111	*Lygodioisporites*	*verrucosus*	X				
112	*Matonisporites*	*crassiangulatus*	X				
113	*Microfoveolatosporis*	*pseudoreticulatus*	X			X	
114	*Microreticulatisporites*	*crassiexinous*	X				
115	*M.*	*diatretus*	X				
116	*M.*	*uniformis*	X				
117	*M.*	sp.	X		X		
118	*Neoraistrickia*	*truncata*	X		X	X	
119	*N.*	spp.	X			X	
120	*Ornamentifera*	*baculata*	X		X		
121	*O.*	*echinata*	X			X	
122	*Osmundacites*	*wellmanii*	X				
123	cf. *Pilosisporites*	*trichopapillosus*	X				
124	*P.*	sp.	X				

Table 39 continued

	SPORES						
	Genus	**Species**	**A-F**	**G**	**H**	**I**	**J**
125	*Polycingulatisporites*	*reduncus*	X			X	
126	*Polypodiidites*	spp.	X				
127	*Psilatriletes*	*radiatus*	X				
128	*Reticulatasporites*	*dupliexinous*	X				
129	*Reticulisporites*	*semireticulatus*	X				
130	*Reticuloidosporites*	*pseudomurii*	X				
131	*Retitriletes*	*austroclavatidites*	X			X	
132	*R.*	*clavatoides*	X				
133	*R.*	*crassimacerius*	X				
134	*R.*	*lucifer*	X				
135	*R.*	*singhii*	X				
136	*R.*	*subreticulaesporites*	X			X	
137	*R.*	sp.	X				
138	cf. *R.*	*subreticulaesporites*			X		
139	Rouseisporites	*triangularis*	X				
140	*Schizaeoisporites*	sp.	X				
141	*Schizea*	*reticulata*	X				
142	*Selaginella*	*simplex*	X				
143	*Sestrosporites*	*pseudoalveolatus*				X	
144	*Stereiosporites*	*antiquasporites*	X				
145	*Taurocusporites*	*segmentatus*	X				
146	cf. *T.*	*segmentatus*	X				
147	*Todisporites*	*minor*	X				
148	*T.*	sp.	X			X	
149	*Toroisporis*	*delicatus*	X				
150	*Trianchoraeosporites*	*reticulatus*	X			X	
151	*Triplanosporites*	*sinuosus*	X				
152	*Triporoletes*	*radiatus*	X				
153	*Umbosporites*	*callosus*				X	
154	*Undulatisporites*	*fossulatus*	X		X		
155	*Verrucosisporites*	*major*	X				
156	*V.*	spp.	X				
157	Unknown	spp.	X		X	X	X

Table 39 continued

	POLLEN		A-F	G	H	I	J
	Genus	Species					
1	*Abiespollenites*	spp.	X			X	
2	*Abietineaepollenites*	*microreticulatus*	X				
3	*A.*	*varius*	X		X		
4	*A.*	sp.		X			
5	*Abietipites*	sp.	X				X
6	*Accuratipollis*	*evanidtus*	X				
7	*Alisporites.*	*bilateralis*	X		X		
8	*A.*	*grandis*	X		X		
9	*A.*	cf. *bilateralis*	X				
10	cf. *A.*	*bilateralis*		X			
11	*A.*	cf. *microsaccus*			X		
12	*Alnipollenites*	*verus*				X	
13	*A.*	sp.	X				
14	*Alnus*	*incana*	X				
15	cf. *Anacolosidites*	spp.	X				
16	*Aquilapollenites*	*augustus*	X				
17	*A.*	*bertillonites*	X				
18	*A.*	*conatus*	X			X	
19	*A.*	*contiguus*	X				
20	*A.*	*delicatus*	X				
21	*A.*	*delicatus* var. *delicatus*	X			X	
22	*A.*	*notabile*	X	X			
23	*A.*	*polaris*	X			X	
24	*A.*	*quadrilobus*	X				X
25	*A.*	*reticulatus*					X
26	*A.*	*scabratus*	X				
27	*A.*	*senonicus*	X	X			X
28	*A.*	*spinulosus*	X	X		X	
29	*A.*	*trialatus*	X			X	
30	*A.*	sp.	X				
31	*A.*	cf. *delicatus*	X				
32	*A.*	cf. *catenireticulatus*	X				
33	*A.*	cf. *polaris*	X				
34	*A.*	cf. *reticulatus*				X	
35	*Beaupreadites*	*elegansiformis*				X	
36	*Betulaepollenites*	spp.	X			X	

Table 39 continued

	POLLEN		A-F	G	H	I	J
	Genus	**Species**					
37	*Boehlensipollis*	sp.	X				
38	*Bombacacipites*	spp.					X
39	*Bombacacipites*	cf. *nacimientoensis*	X				
40	*Callistopollenites*	*comis*	X				
41	*C.*	*radiostriatus*				X	
42	Cedripites	canadensis	X		X		
43	*C.*	*cretaceus*	X				
44	*C.*	*parvus*				X	
45	*C.*	cf. *parvus*	X				
46	*C.*	spp.	X	X		X	X
47	*Cranwellia*	*rumseyensis*	X				X
48	*C.*	*striata*	X	X			
49	*Cupanieidites*	*major*				X	
50	*C.*	*terrestris*	X				
51	*Cycadopites*	*reticulatus*		X	X	X	
52	*C.*	sp.	X	X			
53	*Dryadopollis*	sp.	X				
54	*Ephedrapites*	spp.	X	X		X	
55	*Erdmanipollis*	*albertensis*	X				
56	*Eucommiidites*	*troedssonii*	X			X	
57	*E.*	*minor*	X				
58	cf. *Expressipollis*	*ocliferus*				X	
59	*Extraporopollenites*	sp.	X				
60	*Extratriporopollenites*	sp.	X	X		X	
61	*Fraxinoipollenites*	*constrictus*	X			X	X
62	*F.*	sp.	X			X	
63	*Ilexpollenites*	*obscuricostata*	X				
64	*Liliacidites*	*inaequalis*	X	X			
65	*Mancicorpus*	*albertensis*		X			
66	*M.*	*canadiana*	X				
67	*M.*	*pulcher*	X				
68	*M.*	*rostratus*		X			
69	*M.*	sp.	X				X
70	*M.*	cf. *trapeziforme*	X				
71	*M.*	cf. *tripodiformis*		X			

Table 39 continued

	POLLEN		A-F	G	H	I	J
	Genus	**Species**					
72	*Marcellopites*	*basilicus*	X				
73	*Momipites*	*inaequalis*	X				
74	*Myrica*	sp.	X				
75	*Nyssapollenites*	*albertensis*	X			X	
76	*N.*	*bindae*	X				
77	*Nyssoidites*	*anulatus*	X				
78	*Oculopollis*	*orbicularis*				X	
79	*O.*	sp.				X	
80	*Parvisaccites*	*radiatus*	X				
81	*P.*	sp.	X				
82	*P.*	cf. *radiatus*	X				
83	*P.*	cf. *rugulatus*	X				
84	cf. *P.*	*amplus*	X				
85	*Penetetrapites*	*inconspicuus*	X				
86	cf. *P.*	*inconspicuus*	X				
87	*Phyllocladites*	cf. *microreticulatus*	X				
88	*Piceapollenites*	spp.	X	X			
89	*Pinuspollenites*	*constrictus*	X				
90	*P.*	spp.	X			X	
91	*Pityosporites*	*alatipollenites*	X				
92	*P.*	*constrictus*	X	X			
93	*P.*	*elongatus* var. *elongatus*				X	
94	*P.*	*elongatus* var. *grandis*	X				
95	*P.*	sp.			X		
96	*P.*	*alatipollenites*					X
97	cf. *P.*	*elongatus* var. *elongatus*					X
98	*Platysaccus*	spp.	X				
99	*Podocarpidites*	*biformis*	X		X		
100	*P.*	*canadensis*	X	X	X		
101	*P.*	*epistratus*				X	
102	*P.*	*granulatus*	X	X	X		
103	*P.*	*minisculus*	X		X	X	
104	*P.*	*multesimus*	X	X	X	X	
105	*P.*	*potomacensis*	X	X			
106	*P.*	*radiatus*	X				

Table 39 continued

	POLLEN		A-F	G	H	I	J
	Genus	Species					
107	*P.*	cf. *canadensis*					X
108	*P.*	cf. *ellipticus*	X				
109	*P.*	cf. *radiatus*	X				
110	*P.*	spp.	X				
111	*Proteacidites*	*auratus*	X	X			
112	*P.*	*retusus*	X			X	
113	*P.*	*thalmanni*	X			X	
114	*P.*	spp.	X			X	
115	cf. *P.*	*retusus*	X				
116	*Quercoidites*	*sternbergi*		X			
117	cf. *Quercus*	*explanata*	X				
118	*Retibrevitrocolporites*	*beccus*				X	X
119	*Retitricolpites*	*georgensis*	X				
120	*R.*	*maximus*	X				
121	*R.*	*vulgaris*	X				
122	*Rousea*	*subtilis*	X				
123	*R.*	sp.	X				
124	*Rugubivesiculites*	*reductus*	X			X	
125	*R.*	cf. *reductus*	X	X			
126	*R.*	spp.	X	X		X	
127	*Scollardia*	*trapaformis*	X				
128	*Sequoia*	*papillapollenites*	X			X	
129	*Spermitites*	spp.	X				
130	*Striatellipollis*	*striatella*	X				
131	*Taxodiaceaepollenites*	*hiatus*	X	X		X	X
132	*T.*	*vacuipites*	X				
133	*Tilia*	cf. *wodehousei*	X				
134	*Tricolpate*	spp.			X		X
135	*Tricolpites*	*micromunus*	X				
136	*T.*	*microreticulatus*	X				
137	*T.*	*reticulatus*	X				
138	*T.*	cf. *parvus*	X				
139	*Triprojectate*	sp.			X		
140	*Triporate*	sp.		X			
141	*Triporopollenites*	cf. *mullensis*					X
142	*Trudopollis*	*hemiperfectus*				X	

Table 39 continued

	POLLEN		A-F	G	H	I	J
	Genus	**Species**					
143	*T.*	*pertrudens*	X				
144	*Ulmoideipites*	*herbridicus*	X				
145	*Vitreisporites*	*pallidus*	X		X	X	
146	*V.*	sp.	X				
147	cf. *V.*	*pallidus*			X		
148	*Wodehouseia*	*capillata*	X				
149	*W.*	*gracile*	X				
150	Unknown	spp.	X				

Table 40

Palynomorphs from collection sites A through F, Mazuma Creek

	FUNGAL SPORES							
	Genus	**Species**	**A**	**B**	**C**	**D**	**E**	**F**
1	*Colligerites*	*kutchensis*				X		
2	*Dyadosporites*	*substrangulatus*				X		
3	*Fusiformisporites*	*rugosus*				X		
4	*Palambages*	*canadiana*			X			
5	*Pluricellaesporites*	*magnus*				X		
6	*Pluricellaesporites*	*sheffyi*				X		
7	*Tetraporina*	sp.		X				

	WOOD CELLS	A	B	C	D	E	F
1	cf. *Araucarioxylon*		**X**				
2	cf. *Ginkgo*						**X**
3	cf. *Pinus*				**X**		**X**
4	cf. *Podocarpus*						**X**
5	cf. *Sequoia*						**X**
6	cf. *Taxodium*						**X**
7	Unidentified Wood		**X**		**X**		**X**

	SPORES							
	Genus	**Species**	**A**	**B**	**C**	**D**	**E**	**F**
1	*Acanthotriletes*	*varispinosus*		X				
2	cf. *Anemia*	*paradoxa*	X					
3	*Appendicisporites*	*bilateralis*					X	
4	*A.*	*potomacensis*	X					
5	*Aequitriradites*	*spinulosus*						X
6	*Baculatisporites*	*comaumensis*	X		X	X	X	
7	*B.*	spp.	X		X	X		
8	*Biretisporites*	*potoniaei*			X	X		
9	*B.*	*psilatus*	X					X
10	*B.*	cf. *potoniaei*			X	X		
11	*Brevimonosulcites*	*corrugatus*						X
12	cf. *Brevimonosulcites*	*corrugatus*						X

Table 40 continued

	SPORES							
	Genus	Species	A	B	C	D	E	F
13	*Calamospora*	sp.				X		
14	*Camarozonosporites*	*ambigens*			X			
15	*C.*	*australiensis*		X				
16	*C.*	*insignis*	X	X	X	X	X	X
17	*C.*	sp.		X				
18	*Ceratosporites*	*equalis*					X	
19	*C.*	*levidensis*		X				
20	*C.*	cf. *couliensis*		X	X			
21	*Cibotiumspora*	*juncta*	X					X
22	*C.*	*jurienensis*			X			
23	*Cicatricosisporites*	*augustus*						X
24	*C.*	*annulatus*		X				
25	*C.*	*hallei*			X			
26	*C.*	*hughesi*				X		
27	*C.*	*imbricatus*	X		X			
28	*C.*	*ornatus*				X		X
29	*C.*	*pseudotripartitus*		X	X			
30	*C.*	*radiatus*	X		X	X		X
31	*C.*	spp.	X	X	X	X	X	X
32	*C.*	cf. *annulatus*						X
33	*C.*	cf. *hallei*	X					X
34	*C.*	cf. *imbricatus*				X		X
35	*Cingulatisporites*	*reticingulus*	X					
36	*Cingutriletes*	*clavus*		X	X			
37	*C.*	sp.			X			
38	*Conbaculatisporites*	sp.			X			
39	*Concavisporites*	sp.			X			
40	*Concavissimisporites*	cf. *minor*						X
41	*C.*	spp.	X		X			X
42	*Concavitriletes*	*mesozoicus*						X
43	*Converrucosporites*	sp.				X		
44	*Converrucosisporites*	cf. *cameronii*				X	X	
45	*Cornutisporites*	*seebergensis*				X		
46	*Cyathidites*	*australis*	X	X	X	X	X	X
47	*C*	*diaphana*						X
48	*C.*	*minor*	X	X	X	X		X

Table 40 continued

	SPORES							
	Genus	**Species**	**A**	**B**	**C**	**D**	**E**	**F**
49	*C.*	spp.						X
50	*Deltoidospora*	*hallii*	X		X	X		X
51	*D.*	*juncta*				X	X	
52	*D.*	*neddeni*	X	X	X	X	X	
53	*D.*	*psilostoma*		X				X
54	*D.*	spp.	X	X	X	X	X	X
55	*Dictyophyllidites*	*mortonii*	X	X	X	X		
56	*D.* spp.				X		X	X
57	*Distaltriangulispor-ites*	*perplexus*	X	X	X	X	X	X
58	*D.*	*mutabilis*						X
59	cf. *Duplosporis*	*ocliferus*				X		
60	*Echinatisporis*	*solaris*			X			
61	*E.*	spp.		X			X	X
62	*Echinosporis*	sp.						X
63	*Foraminisporis*	*simiscalaris*	X	X				
64	*F.*	*wonthaggiensis*			X			X
65	*Foraminisisporis*	*undulatus*	X					
66	*Foveasporis*	*linearis*						X
67	*F.*	cf. *linearis*			X	X		X
68	*Foveogleicheniidites*	*confossus*			X		X	X
69	*Foveosporites*	*crassus*						X
70	*F.*	*subtriangularis*				X		X
71	*F.*	spp.		X	X	X		
72	*Foveotriletes*	*palaequestrus*						X
73	*Gemmatriletes*	*morulus*			X			
74	*Gleicheniidites*	*circinidites*	X	X	X	X		X
75	*G.*	*concavisporites*		X				
76	*G.*	*delicatus*			X		X	
77	*G.*	*senonicus*			X	X	X	X
78	*G.*	*umbonatus*		X	X	X	X	
79	*G*	cf. *senonicus*				X		
80	*G.*	spp.	X	X	X	X		X
81	*Hamulatisporis*	*amplus*	X	X	X			
82	*Hazaria*	*canadiana*		X		X		

Table 40 continued

	SPORES							
	Genus	**Species**	**A**	**B**	**C**	**D**	**E**	**F**
83	*Hymenoreticulispor-ites*	*castallatus*			X			
84	*Interulobites*	*crassiexinous*						
85	*I.*	cf. *intraverrucatus*			X			
86	*I.*	sp.				X		
87	*Klukisporites*	*pseudoreticulatus*			X			
88	*Krauselisporites*	*cuspidus*						X
89	*K.*	*hastilobatus*					X	X
90	*K.*	*reissingerii*			X			X
91	*Laevigatosporites*	*gracilis*		X	X			
92	*L.*	*ovatus*			X			
93	*L.*	spp.	X		X	X	X	X
94	*Leptolepidites*	*crepitus*	X				X	
95	*L.*	*verrucatus*		X		X		X
96	*Lycopodiacidites*	*canaliculatus*			X	X		X
97	*L.*	*caperatus*		X	X			
98	*L.*	sp.	X					
99	*Lycopodiumsporites*	*crassatus*			X			
100	*L.*	*crassimacerius*		X	X	X		X
101	*L.*	*carginatus*	X		X			X
102	*L.*	*reticulumsporites*						
103	*L.*	*singhii*		X				
104	*L.*	spp.		X		X		X
105	*Lygodium*	sp.	X					
106	*Lygodioisporites*	*verrucosus*		X	X			
107	*Matonisporites*	*crassiangulatus*		X				
108	*Microfoveolatosporis*	*pseudoreticulatus*			X			
109	*Microreticulatispor-ites*	*crassiexinous*			X			
110	*M.*	*diatretus*				X		
111	*M.*	*uniformis*						X
112	*M.*	sp.	X					
113	*Neoraistrickia*	*truncata*	X		X	X		
114	*N.*	spp.			X			X

Table 40 continued

	SPORES							
	Genus	**Species**	**A**	**B**	**C**	**D**	**E**	**F**
115	*Ornamentifera*	*baculata*				X		X
116	*O.*	*echinata*						X
117	*Osmundacites*	*wellmanii*				X		X
118	cf. *Pilosisporites*	*trichopapillosus*				X		
119	*P.*	sp.			X			X
120	*Polycingulatisporites*	*reduncus*	X			X		X
121	*Polypodiidites*	spp.	X	X	X	X		X
122	*Psilatriletes*	*radiatus*				X	X	X
123	*Reticulatasporites*	*dupliexinous*	X		X			
124	*Reticulisporites*	*semireticulatus*			X		X	
125	*Reticuloidosporites*	*pseudomurii*				X		
126	*Retitriletes*	*austroclavatidites*	X	X		X		
127	*R.*	*clavatoides*	X	X	X		X	
128	*R.*	*crassimacerius*		X				
129	*R.*	*lucifer*	X					
130	*R.*	*singhii*	X		X	X		
131	*R.*	*subreticulaespor-ites*	X	X	X		X	X
132	*R.*	sp.			X			
133	*Rouseisporites*	*triangularis*			X			
134	*Schizaeoisporites*	sp.						X
135	*Schizea*	*reticulata*	X	X	X	X		
136	*Selaginella*	*simplex*				X		
137	*Stereiosporites*	*antiquasporites*	X	X	X	X		X
138	*Taurocusporites*	*segmentatus*	X	X	X	X	X	X
139	cf. *T.*	*segmentatus*				X		
140	cf. *Tetrasporina*	sp.		X				
141	*Todisporites*	*minor*						X
142	*T.*	sp.	X		X			
143	*Toroisporis*	*delicatus*					X	
144	*Triancoraeosporites*	*reticulatus*				X		X
145	*Triplanosporites*	*sinuosus*	X					
146	*Triporoletes*	*radiatus*			X			X
147	*Undulatisporites*	*fossulatus*	X	X	X	X	X	X
148	*Verrucosisporites*	*major*	X		X			
149	*V.*	spp.	X	X		X		X
150	Unknown genera			X		X		X

Table 40 continued

	POLLEN							
	Genus	**Species**	**A**	**B**	**C**	**D**	**E**	**F**
1	*Abiespollenites*	spp.	X	X	X	X		X
2	*Abietineaepollenites*	*microreticulatus*			X			
3	*A.*	*varius*			X			
4	*Abietipites* sp.		X	X	X			X
5	*Accuratipollis*	*evanidtus*	X			X		
6	*Alisporites*	*grandis*	X	X	X			X
7	*Alisporites*	*bilateralis*				X		
8	*A.*	cf. *bilateralis*	X				X	
9	*Alnipollenites* sp.					X		
10	*Alnus*	*incana*					X	
11	cf. *Anacolosidites*	spp.	X		X			
12	*Aquilapollenites*	*augustus*			X			X
13	*A.*	*bertillonites*				X		
14	*A.*	*conatus*				X		
15	*A.*	*contiguus*				X		
16	*A.*	*delicatus*		X				
17	*A.*	*delicatus* var. *delicatus*				X		
18	*A.*	*notabile*	X			X		
19	*A.*	*polaris*	X					
20	*A.*	*quadrilobus*	X					
21	*A.*	*scabratus*				X		
22	*A.*	*senonicus*		X		X	X	
23	*A.*	*spinulosus*	X		X	X		X
24	*A.*	*trialatus*				X		
25	*A.*	sp.				X		
26	*A.*	cf. *delicatus*	X					
27	*A.*	cf. *cateniretic u - latus*					X	
28	*A.*	cf. *polaris*						X
29	*Betulaepollenites*	sp.				X		X
30	*Boehlensipollis*	sp.						X
31	*Bombacacipites*	cf. *nacimientoensis*				X		
32	*Callistopollenites*	*comis*	X					
33	*Cedripites*	*canadensis*			X	X		

Table 40 continued

	POLLEN							
	Genus	**Species**	**A**	**B**	**C**	**D**	**E**	**F**
34	*C.*	*cretaceus*			X	X		
35	*C.*	cf. *parvus*					X	
36	*C.*	spp.					X	X
37	*Cranwellia*	*rumseyensis*	X			X		X
38	*C.*	*striata*	X	X		X		
39	*Cupanieidites*	*terrestris*				X		
40	*Cycadopites*	*reticulatus*		X	X	X		
41	*C.*	sp.		X				
42	*Dryadopollis*	sp.				X		
43	*Ephedrapites*	spp.	X	X		X		
44	*Erdmanipollis*	*albertensis*	X		X			
45	*Eucommiidites*	*troedssonii*				X		
46	*E.*	*minor*				X		
47	*Extraporopollenites*	sp.	X	X	X	X	X	X
48	*Extratriporo-pollenites*	sp.				X		
49	*Fraxinoipollenites*	*constrictus*				X		
50	*F.*	sp.				X		
51	*Ilexpollenites*	*obscuricostata*				X		
52	*Liliacidites*	*inaequalis*				X		
53	*Mancicorpus*	*canadiana*				X		
54	*M.*	*pulcher*		X				
55	*M.*	sp.				X		
56	*M.*	cf.*trapeziforme*				X		
57	*Marcellopites*	*basilicus*	X					
58	*Momipites*	*inaequalis*				X		
59	*Myrica*	sp.	X				X	
60	*Nyssapollenites*	*albertensis*				X		
61	*N.*	*bindae*				X		
62	*Nyssoidites*	*anulatus*				X		
63	*Parvisaccites*	*radiatus*			X			X
64	*P.*	sp.						X
65	*P.*	cf. *radiatus*				X		
66	*P.*	cf. *rugulatus*	X			X	X	
67	cf. *P.*	*amplus*			X			
68	*Penetetrapites*	*inconspicuus*		X	X	X	X	

Table 40 continued

	POLLEN							
	Genus	**Species**	**A**	**B**	**C**	**D**	**E**	**F**
69	cf. *P.*	*inconspicuus*				X		
70	*Phyllocladites*	cf. *microreticulatus*				X		
71	*Piceapollenites*	spp.	X		X	X	X	X
72	*Pinuspollenites*	*constrictus*						X
73	*Pinuspollenites*	spp.			X	X	X	X
76	*Pityosporites*	*alatipollenites*						X
77	*P.*	*constrictus*	X					
78	*P.*	*elongatus* var. *grandis*	X		X			X
79	*Platysaccus*	spp.				X		X
81	*Podocarpidites.*	*biformis*			X			
82	*P.*	*canadensis*			X			X
83	*P.*	*granulatus*	X	X	X	X		X
84	*P.*	*minisculus*			X			X
85	*P.*	*multesimus*	X		X	X		
86	*P.*	*potomacensis*			X			X
87	*P.*	*radiatus*				X		
88	*P.*	cf. *ellipticus*	X	X		X		
89	*P.*	cf. *radiatus*	X	X				
90	*P.*	spp.		X				
91	*Proteacidites*	*auratus*			X	X		
92	*P.*	*retusus*			X	X		
93	*P.*	*thalmanni*	X	X		X		X
94	*P.*	sp.	X					
95	cf. P.	*retusus*						X
96	cf. *Quercus*	*explanata*	X			X		
97	*Retitricolpites*	*georgensis*			X	X		
98	*R.*	*maximus*	X			X		
99	*R.*	*vulgaris*		X		X		
100	*Rousea*	*subtilis*		X	X			
101	*R.*	sp.	X					
102	*Rugubivesiculites*	*reductus*	X					
103	*R.*	sp.						X
104	*R.*	cf. *reductus*						X

Table 40 continued

	POLLEN							
	Genus	**Species**	**A**	**B**	**C**	**D**	**E**	**F**
105	*Scollardia*	*trapaformis*	X	X	X	X		
106	*Sequoia*	*papillapollenites*				X		
107	*Spermatites*	spp.	X	X		X	X	
108	*Striatellipollis*	*striatella*						X
109	*Taxodiaceaepollen-ites*	*hiatus*			X		X	
110	*T.*	*vacuipites*	X					
111	*Tilia*	cf. *wodehousei*	X					
112	*Tricolpites*	*micromunus*				X		
113	*T.*	*microreticulatus*				X		
114	*T.*	*reticulatus*						X
115	*T.*	cf. *parvus*			X			
116	*Trudopollis*	*pertrudens*		X	X			
117	*Ulmoideipites*	*herbridicus*			X	X		X
118	*Vitreisporites*	*pallidus*	X	X		X		
119	*V.*	sp.				X		
120	*Wodehouseia*	*capillata*					X	
121	*W.*	*gracile*	X	X	X	X	X	
122	Unknown	spp.		X	X	X	X	X

Photographic Plates
Mazuma Creek Palynoflora

Plate 1
Florule A-1

Slide No. 94SR (MZ) A001

1. *Stereiosporites antiquasporites* (Wilson and Webster) Dettmann 1963: R9-10, ↑, 3V

2. *Polypodiites* sp.: R9-11, ↑, 4B

3. *Retitriletes clavatoides* (Couper) Doring *et al.* 1963: R9-12, ↑, 7M-N

4. *Lycopodiumsporites marginatus* Singh 1964: R9-28, ↑, 16H

5. *Ephedrapites* sp.: R9-17, ↑, 9W

6. *Cibotiumspora juncta* (Kara-Murza) Singh 1989: R9-9, ↑, 4L

7. *Dictyophyllidites mortonii* (de Jersey) Playford and Dettman 1965: R9-21, ↑, 11U-V

Plate 1

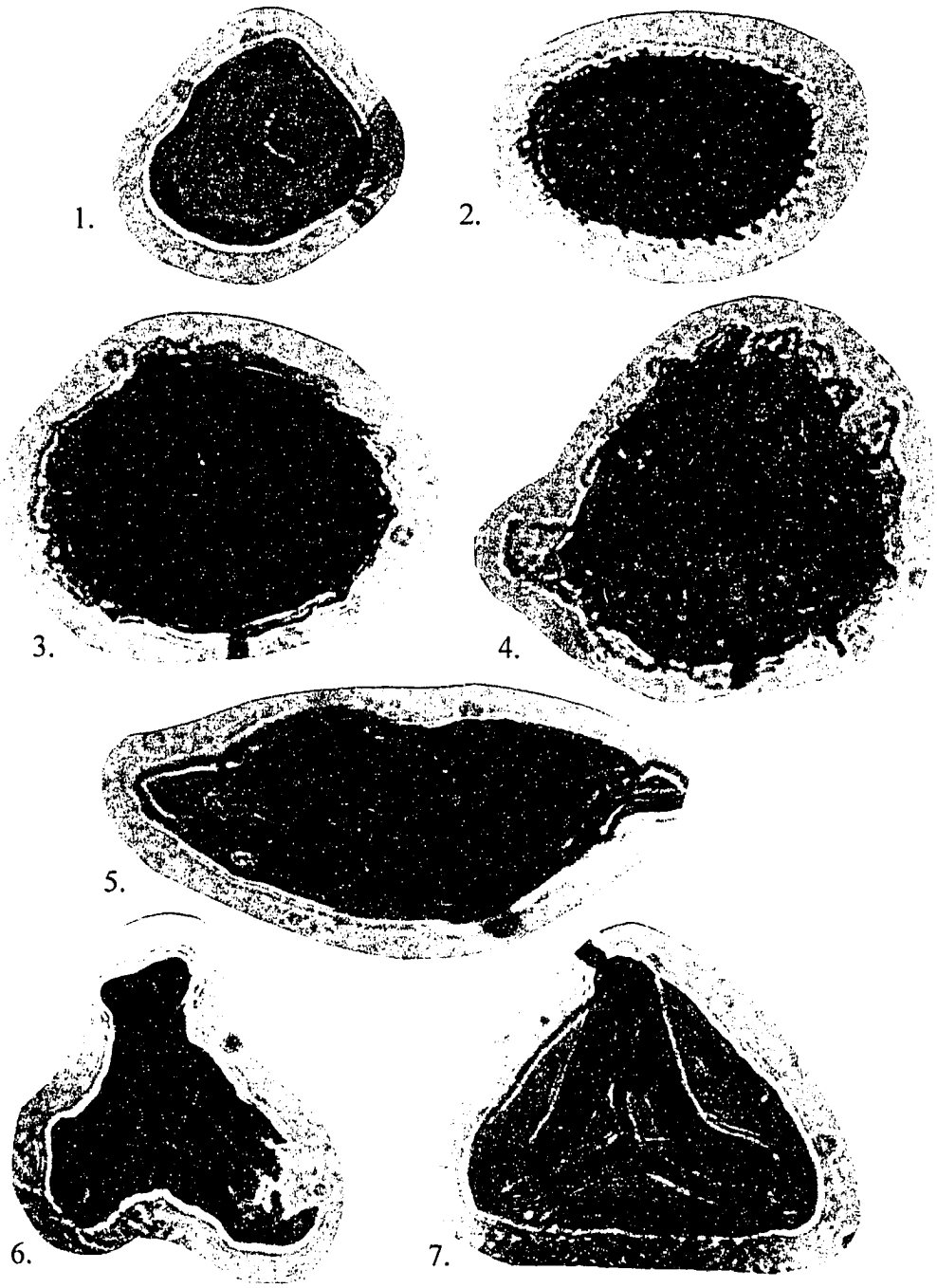


Plate 2

Mazuma Creek Palynoflora
Florule A-1

Slide No. 94SR (MZ) A001

1. *Polycingulatisporites reduncus* (Bolkhovitina) Playford and Dettmann 1965: R9-25, ↑, 14K

2. *Baculatisporites comaumensis* (Cookson) Potonié 1956: R10-36, ↓, 32N

3. *Leptolepidites crepitus* Singh 1971: R10-35, ↓, 34V

4. *Cyathidites minor* Couper 1953: R9-19, ↑, 10D

5. *Deltoidospora neddeni* (Potonié) Orbell 1973: R9-15, ↑, 8W

Plate 2

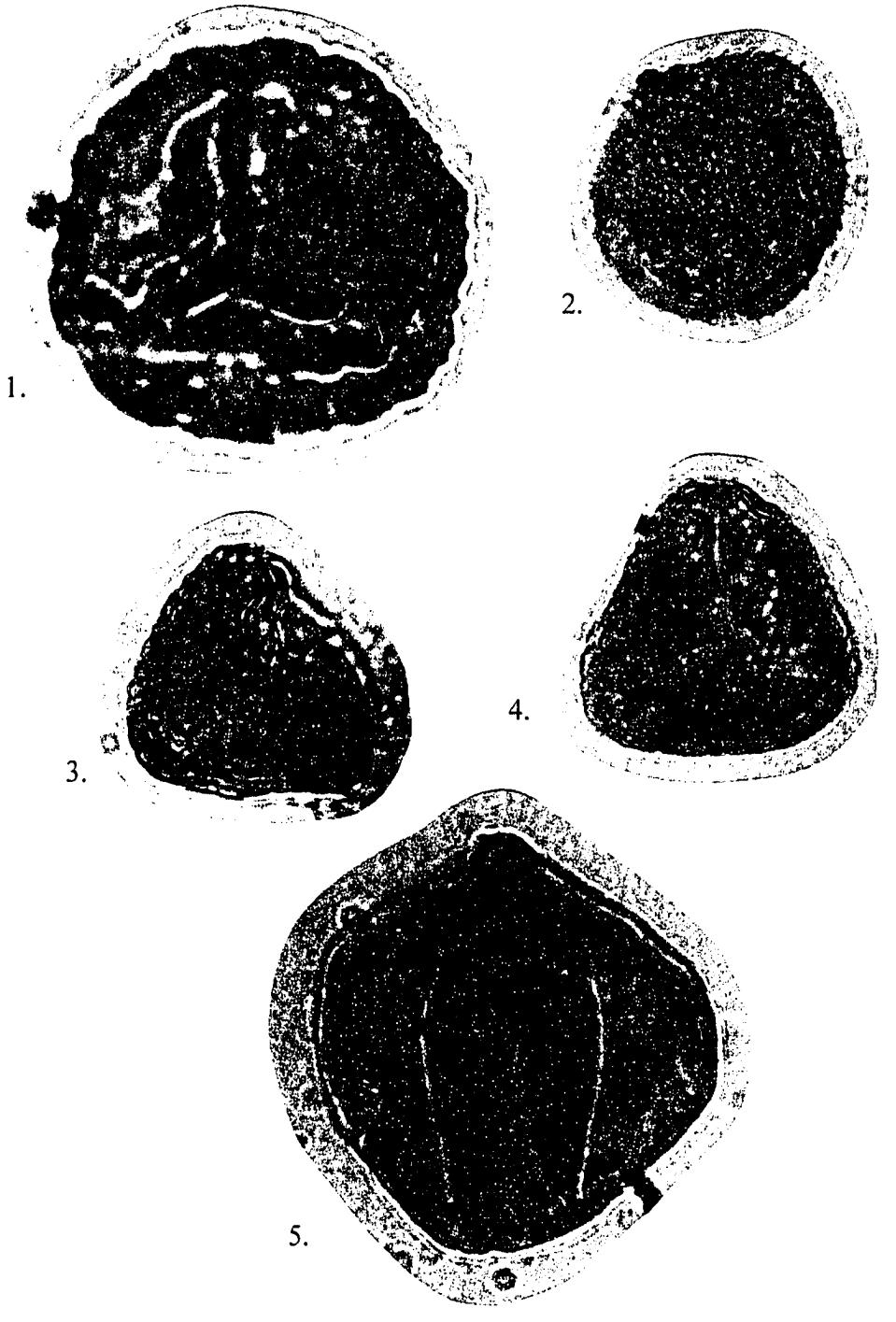


Plate 3

Mazuma Creek Palynoflora
Florule A-1

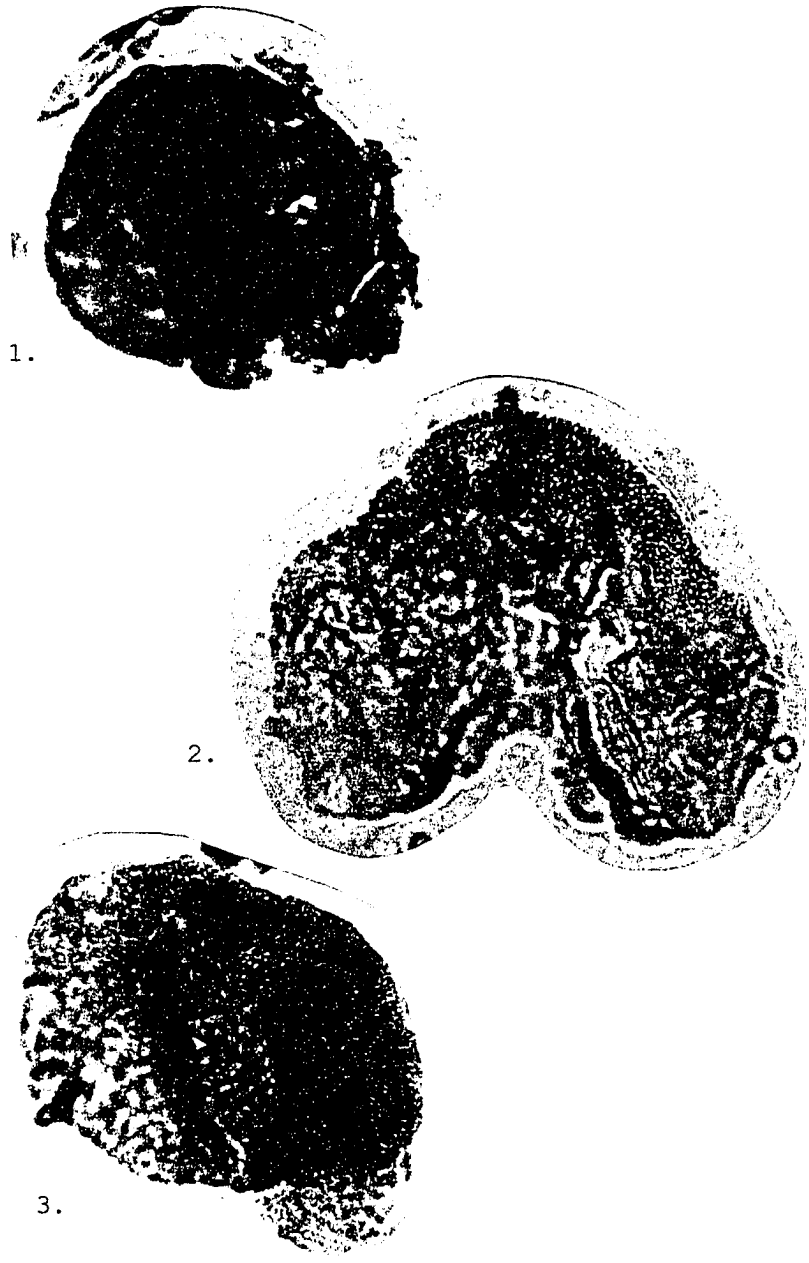
Slide No. 94SR (MZ) A001 (+20)

1. *Parvisaccites* sp. cf. *P. rugulatus* Brenner 1963: R9-5, ↑, 19E-F

2. *Abiespollenites* sp.: R9-8, ↑, 4J

3. *Podocarpidites* sp. cf. *P. radiatus* Brenner 1963: R10-37, ↑, 33U

Plate 3



1.

2.

3.

25 µm

Plate 4

Mazuma Creek Palynoflora
Florule A-1

Slide No. 94SR (MZ) A001 (+20)

1. *Extraporopollenites* sp.: R9-20, ↑, 11U

2. *Spermatites* sp. A, Miner 1935: R9-6, ↑, 1M

Plate 4

1.

2.

25 μm

Plate 5

Mazuma Creek Palynoflora
Florule A-1

Slide No. 94SR (MZ) A001 (+20)

1. *Proteacidites thalmanni* Anderson 1960: R9-1, ↓, 28Q

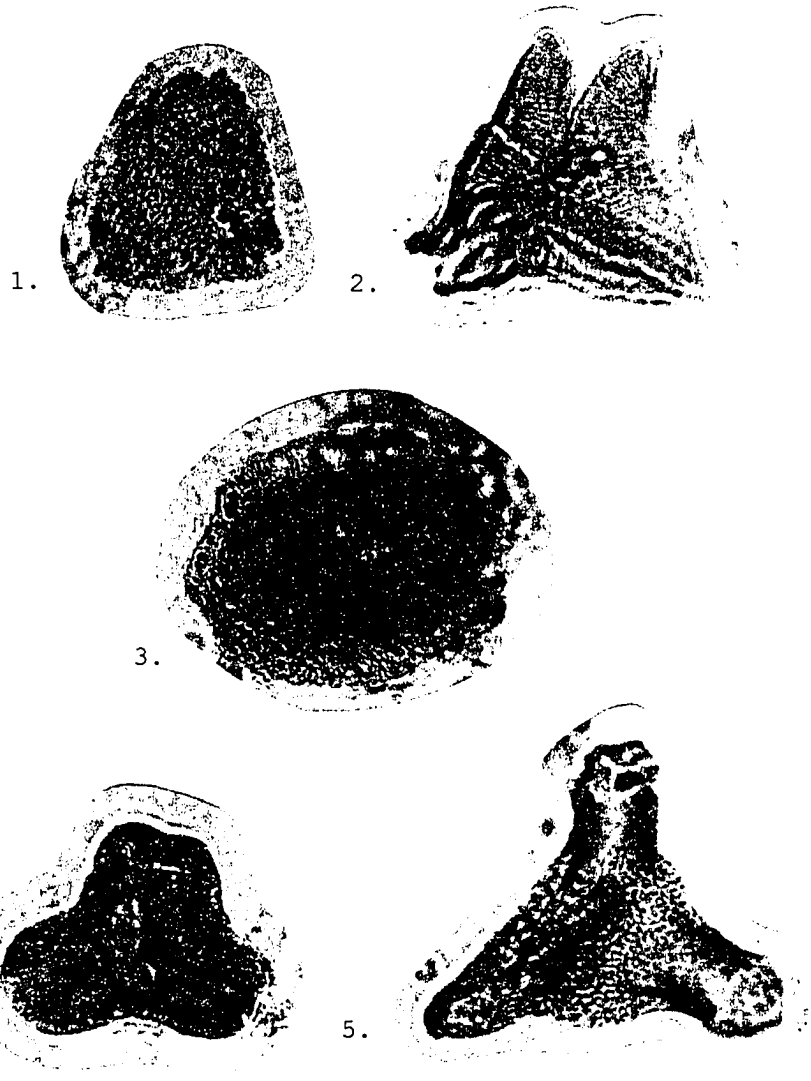
2. *Cranwellia rumseyensis* Srivastava 1966: R9-2, ↓, 23G

3. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: R10-34, ↑, 16V

4. cf. *Anacolosidites* sp.: R9-14, ↑, 6-7R

5. *Aquilapollenites* sp. cf. *A. delicatus* Stanley 1961: R9-3, ↑, 21W

Plate 5



25 µm

Plate 6

Mazuma Creek Palynoflora
Florule A-2

Slide No. 94SR (MZ) A002 (+20)

1. *Polycingulatisporites reduncus* (Bolkhovitina) Playford and Dettman 1965: R10-10, ↓, 18D

2. *Stereisporities* sp.: R10-13, ↑, 3S

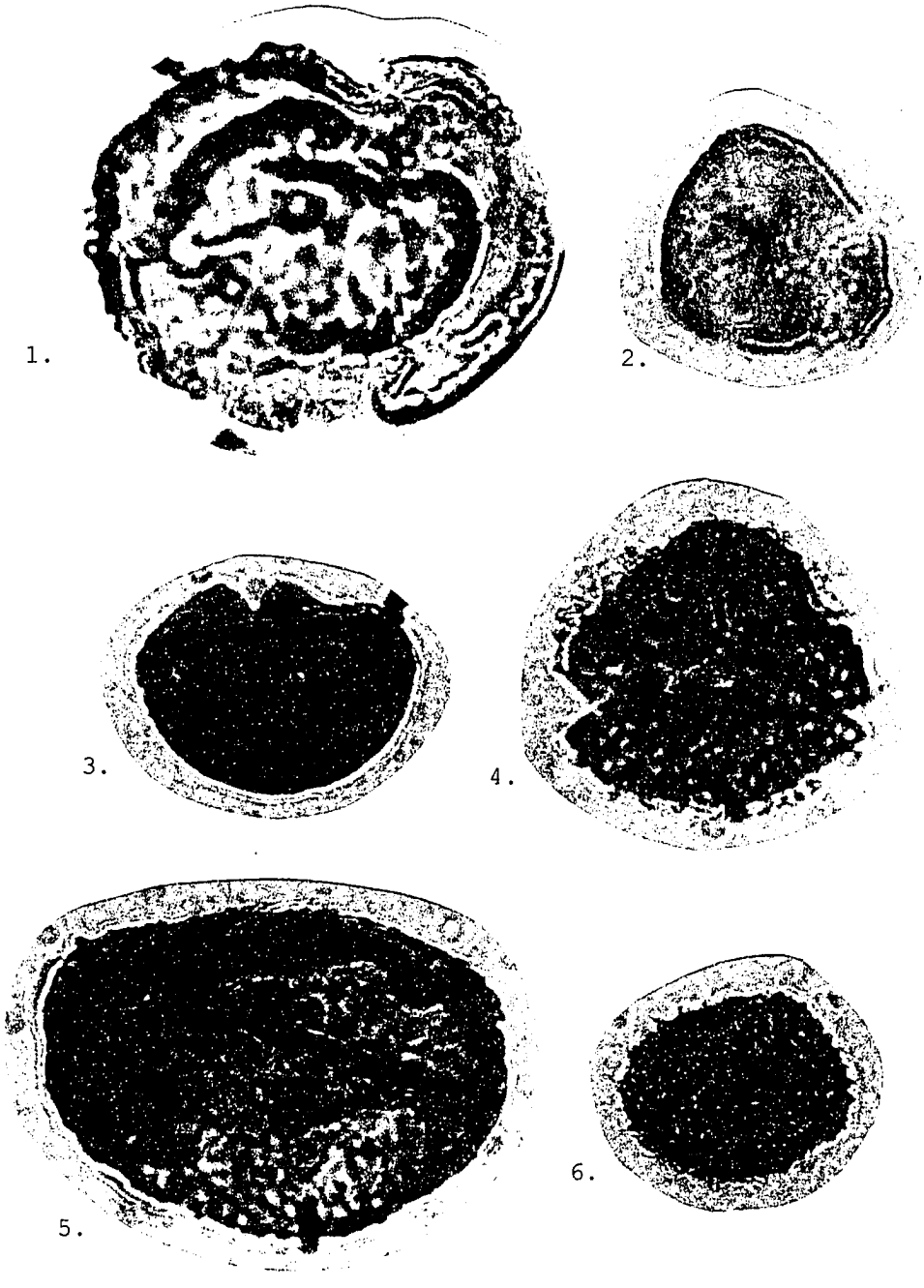
3. *Laevigatosporites* sp.: R10-27, ↑, 12C

4. *Lycopodiacites* sp.: R10-20, ↑, 9-10U

5. *Foraminisporis simiscalaris* (Paden, Phillips and Felix) Braman 2001: R10-3, ↓, 35L

6. *Baculatisporites* sp.: R10-14, ↑, 4V

Plate 6



25 µm

Plate 7

Mazuma Creek Palynoflora
Florule A-2

Slide No. 94SR (MZ) A002 (+20)

1. *Undulatisporites fossulatus* Singh 1971: R10-26, ↑, 11E

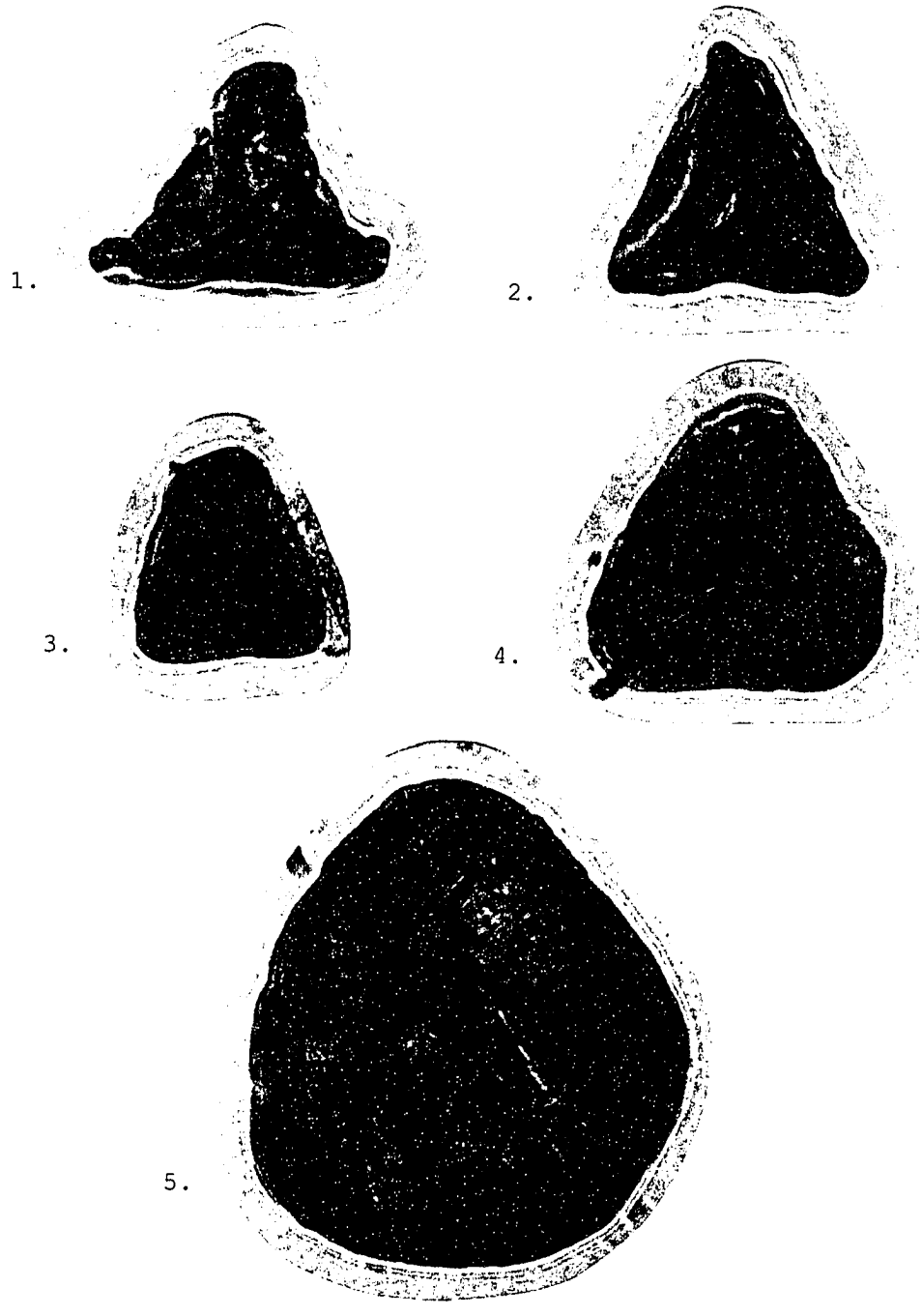
2. *Gleicheniidites circinidites* (Cookson 1953) Dettmann 1963: R10-32, ↑, 17E

3. *Lygodium sp.*: R10-9, ↓, 20E

4. *Deltoidospora* sp.: R10-6, ↓, 31Q

5. *Todisporites* sp.: R10-7, ↑, 22-23Q

Plate 7



25 µm

Plate 8

Mazuma Creek Palynoflora
Florule A-2

Slide No. 94SR (MZ) A002 (+20)

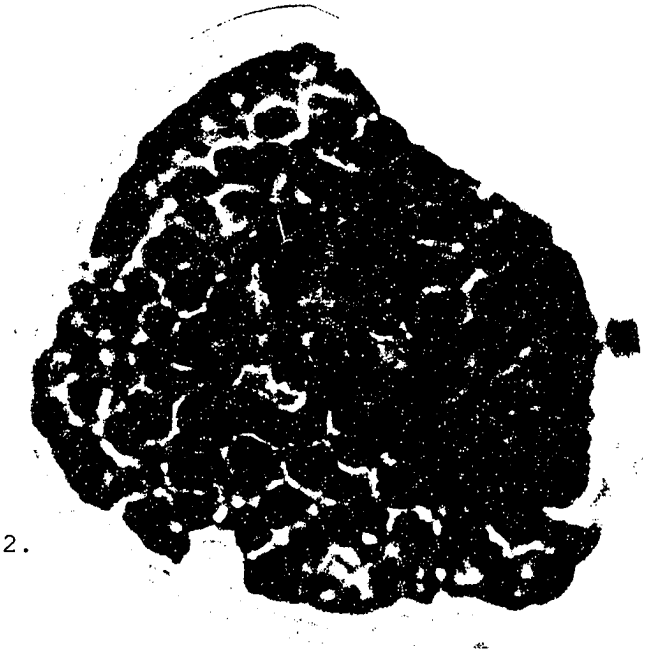
1. *Distaltriangulisporites perplexus* (Singh) Singh 1971: R10-22, ↑, 10X

2. *Taurocuspidites segmentatus* Stover 1962: R10-31, ↑, 15N

Plate 8

1.

2.



25 µm

Plate 9

Mazuma Creek Palynoflora
Florule A-2

Slide No. 94SR (MZ) A002 (+20)

1. *Cicatricosisporites* sp.: R10-30, ↑, 14Q

2. *Taxodiaceaepollenites vacuipites* (Wodehouse) Wingate 1980: R10-24, ↑, 11X

3. *Abietipites* sp.: R10-1, ↑, 36U

Plate 9

Plate 10

Mazuma Creek Palynoflora
Florule A-2

Slide No. 94SR (MZ) A002 (+20)

1. *Piceapollenites* sp.: R10-8, ↓, 21L

2. *Tilia* sp. cf. *T. wodehousei* Anderson 1960: R10-19, ↑, 8V

3. *Proteacidites* sp.: R10-2, ↓, 36M

4. *Accuratipollis evanidus* Chlonova 1961: R10-5, ↓, 33E

5. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: R10-11, ↓, 17J

Plate 10

25 µm

Plate 11

Mazuma Creek Palynoflora
Florule A-3

Slide No. 94SR (MZ) A003

1. *Cingulatisporites reticingulus* Brenner 1963 : R17-12, ↓, 23Q

2. *Gleicheniidites* sp.: R17-11, ↓, 23X

3. *Cyathidites minor* Couper 1953: R17-23, ↑, 4K-L

4. *Baculatisporites comaumensis* (Cookson) Potonié 1956: R17-26, ↑, 7-8C

5. *Retitriletes austroclavatidites* (Cookson) Krutzsch 1963: R17-25, ↑, 5-6F

6. *Retitriletes lucifer* Srivastava 1972: R17-27, ↑, 8-9R

7. *Verrucosisporites* sp.: R17-14, ↓, 22-23M

Plate 11

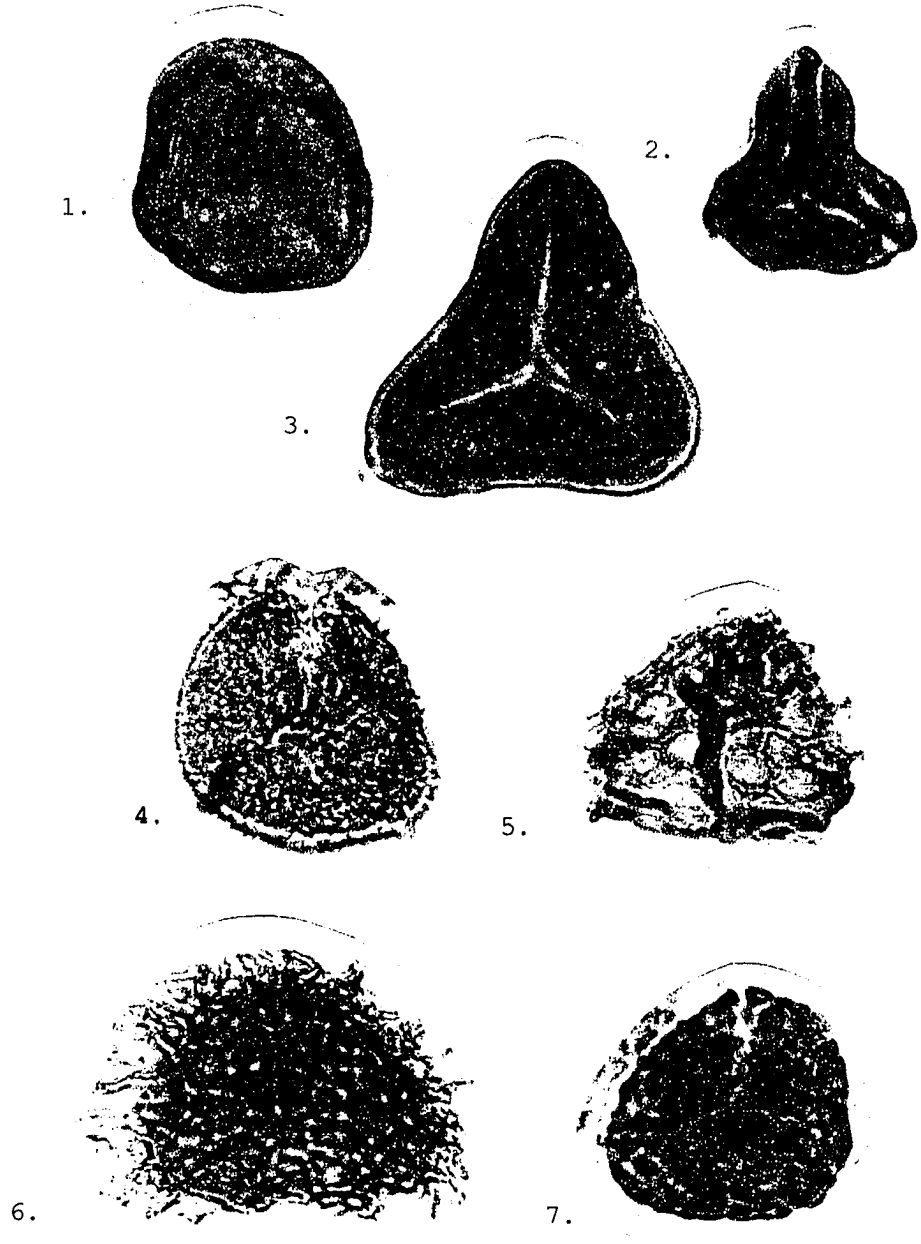


Plate 12

Mazuma Creek Palynoflora
Florule A-4

Slide No. 94SR (MZ) A004

1. *Cicatricosisporites* sp.: R17-24, ↑, 4J

2. *Appendicisporites potomacensis* Brenner 1963: R17-18, ↑, 1H

3. *Polycingulatisporites reduncus* (Bolkhovitina) Playford and Dettmann 1965: R17-20, ↑, 1F

4. *Foraminisporis undulatus* Leffingwell 1971: R14-29, ↓, 22T

5. *Distaltriangulisporites perplexus* (Singh) Singh 1971: R17-13, ↑, 8F

Plate 12

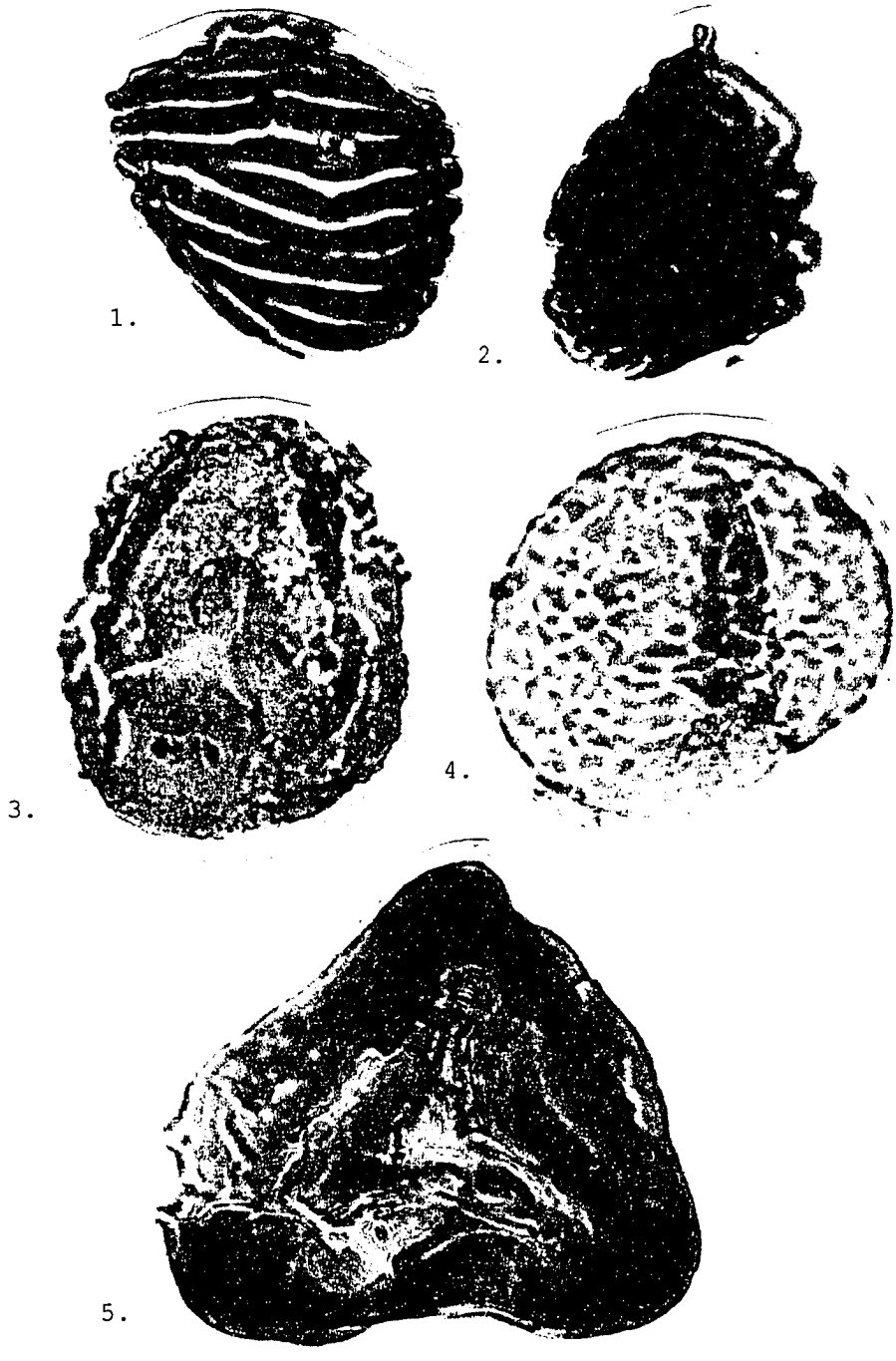


Plate 13

Mazuma Creek Palynoflora
Florule A-3

Slide No. 94SR (MZ) A003

1. *Hamulatisporis amplus* Stanley 1969: R17-34, ↑, 10M-N

2. *Vitreisporites pallidus* (Reissinger) Nilsson 1958: R17-21, ↑, 2N

3. *Abiespollenites* sp.: R17-8, ↓, 26L

4. *Parvisaccites* sp. cf. *P. rugulatus* Brenner 1963: R17-6, ↓, 23G

Plate 13

Plate 14

Mazuma Creek Palynoflora
Florule A-3

Slide No. 94SR (MZ) A003

1. *Abietipites* sp.: R17-17, ↓, 17-18P

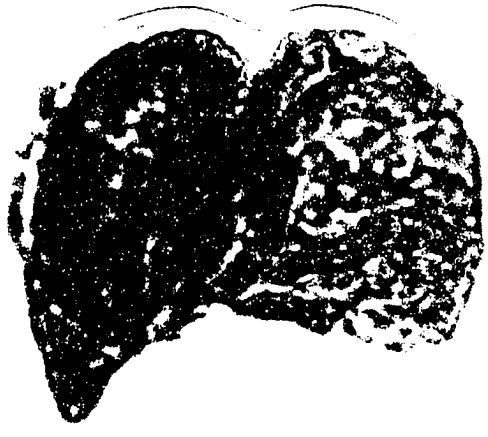
2. *Rugubivesiculites reductus* Pierce 1961: R17-7, ↓, 27U-V

3. *Podocarpidites multesimus* (Bolkhovitina) Pocock 1962: R17-36, ↑, 15K

Plate 14

1.

2.



3.

25 μm

Plate 15

Mazuma Creek Palynoflora
Florule A-3

Slide No. 94SR (MZ) A003

1. *Spermatites* sp.: R17-9, ↓, 24-25K

2. *Rousea* sp.: R17-28, ↑, 9L-M

3. *Marcellopites basilicus* Srivastava 1969: R17-10, ↓, 24L-M

4. *Proteacidites thalmanni* Anderson 1960: R17-30, ↑, 9J

5. *Scollardia trapaformis* Srivastava 1966: R17-4, ↓, 35H

Plate 15

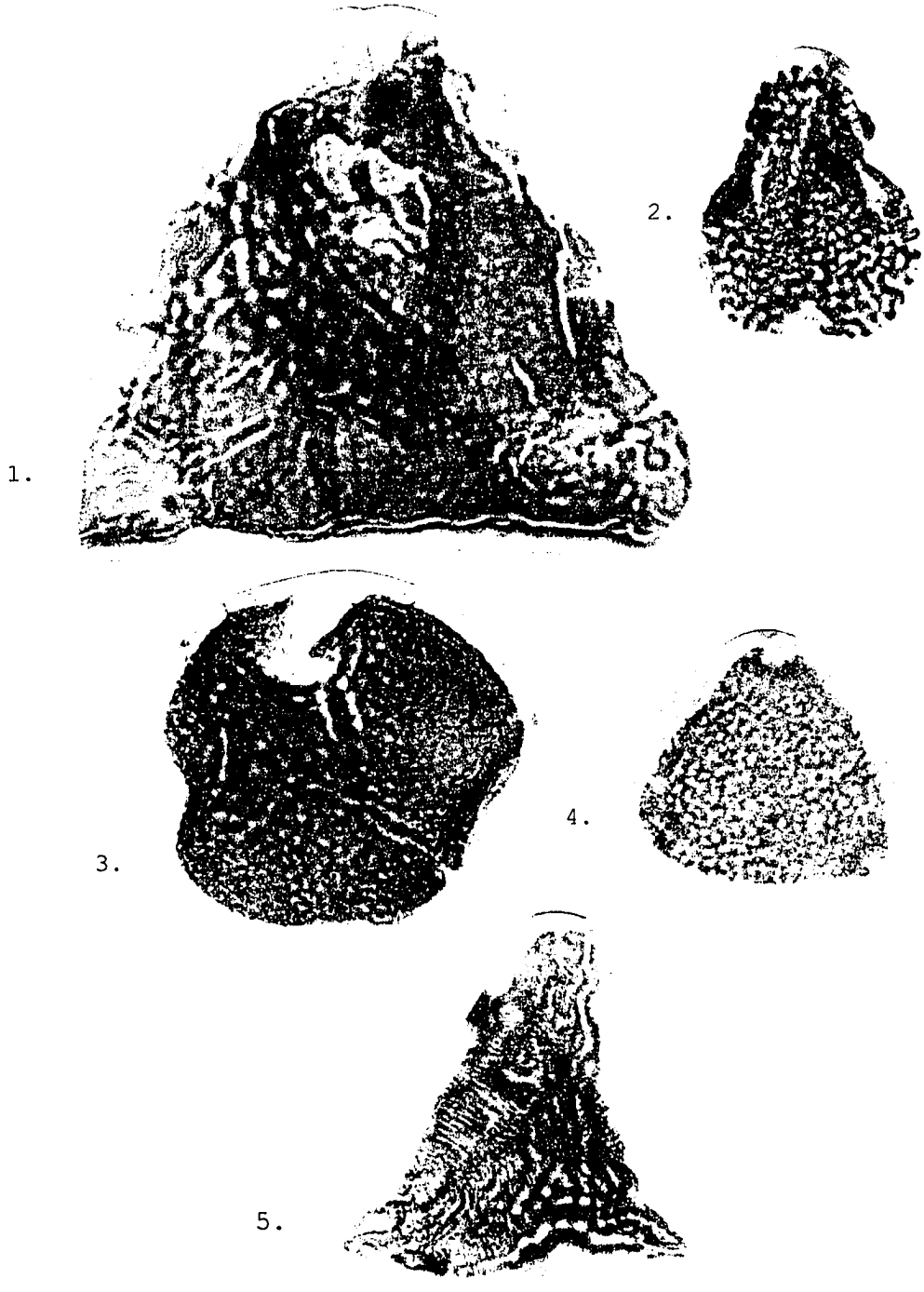


Plate 16

Mazuma Creek Palynoflora
Florule A-3

Slide No. 94SR (MZ) A003

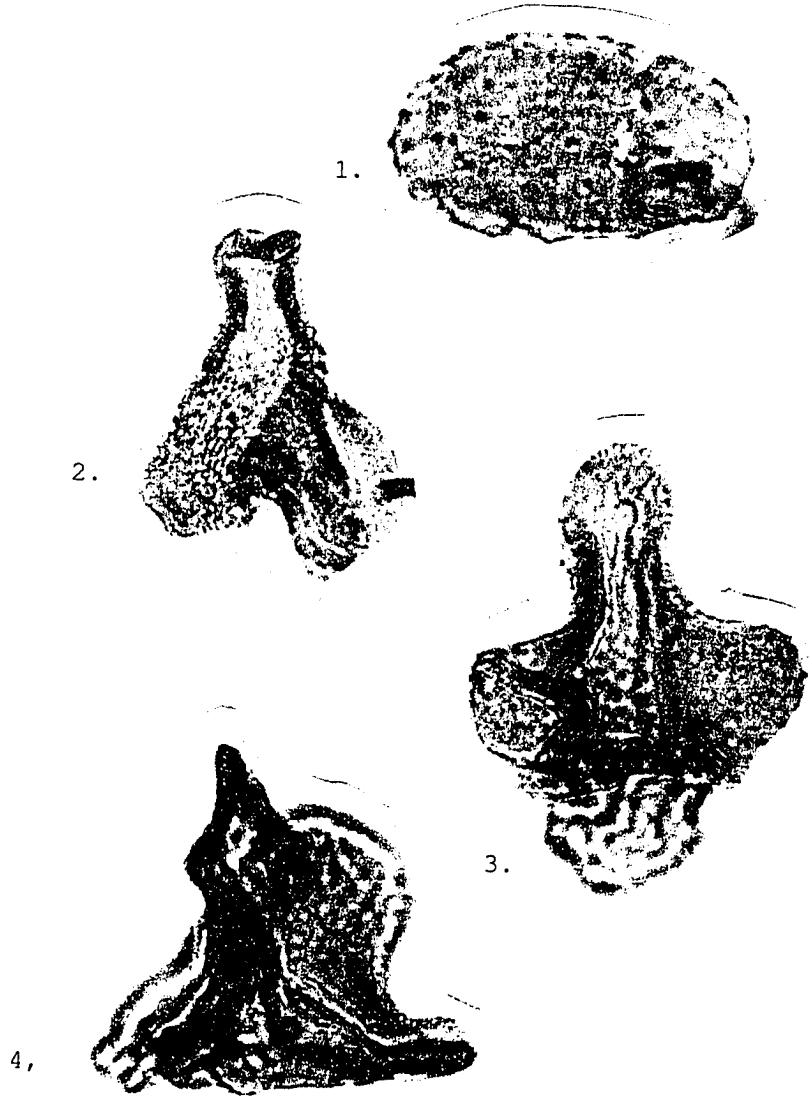
1. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: R17-31, ↑, 9N

2. *Aquilapollenites notabile* (Mtchedlishvili 1961) Farabee 1990: R17-22, ↑, 3C

3. *Aquilapollenites spinulosus* Funkhouser 1961: R17-2, ↓, 36P-Q

4. *Aquilapollenites quadrilobus* Rouse 1957: R17-35, ↑, 10G

Plate 16



25 µm

Plate 17

Mazuma Creek Palynoflora
Florule A-4

Slide No. 94SR (MZ) A004

1. *Stereiosporites antiquasporites* (Wilson and Webster) Dettmann 1963: R18-29, ↑, 10S-T

2. *Reticulatasporites dupliexinous* Brenner 1963: R18-33, ↑, 12E

3. *Retitriletes clavatoides* (Couper) Doring *et al.* 1963: R18-10, ↓, 29K

4. *Polypodiidites* sp.: R18-17, ↓, 19U

5. *Gleicheniidites circinidites* (Cookson) Brenner 1963: R18-9, ↓, 30G

6. *Deltoidospora hallii* Miner 1935: R18-16, ↓, 20F

7. *Cyathidites minor* Couper 1953: R18-35, ↑, 14R-S

8. *Biretisporites psilatus* (Groot and Penny) Dettmann 1963: R18-34, ↑, 15Q

9. *Verrucosisporites major* (Couper) Burden and Hills 1989: R18-30, ↑, 11G

10. *Neoraistrickia truncata* (Cookson) Potonié 1956: R18-4, ↓, 32U

Plate 17

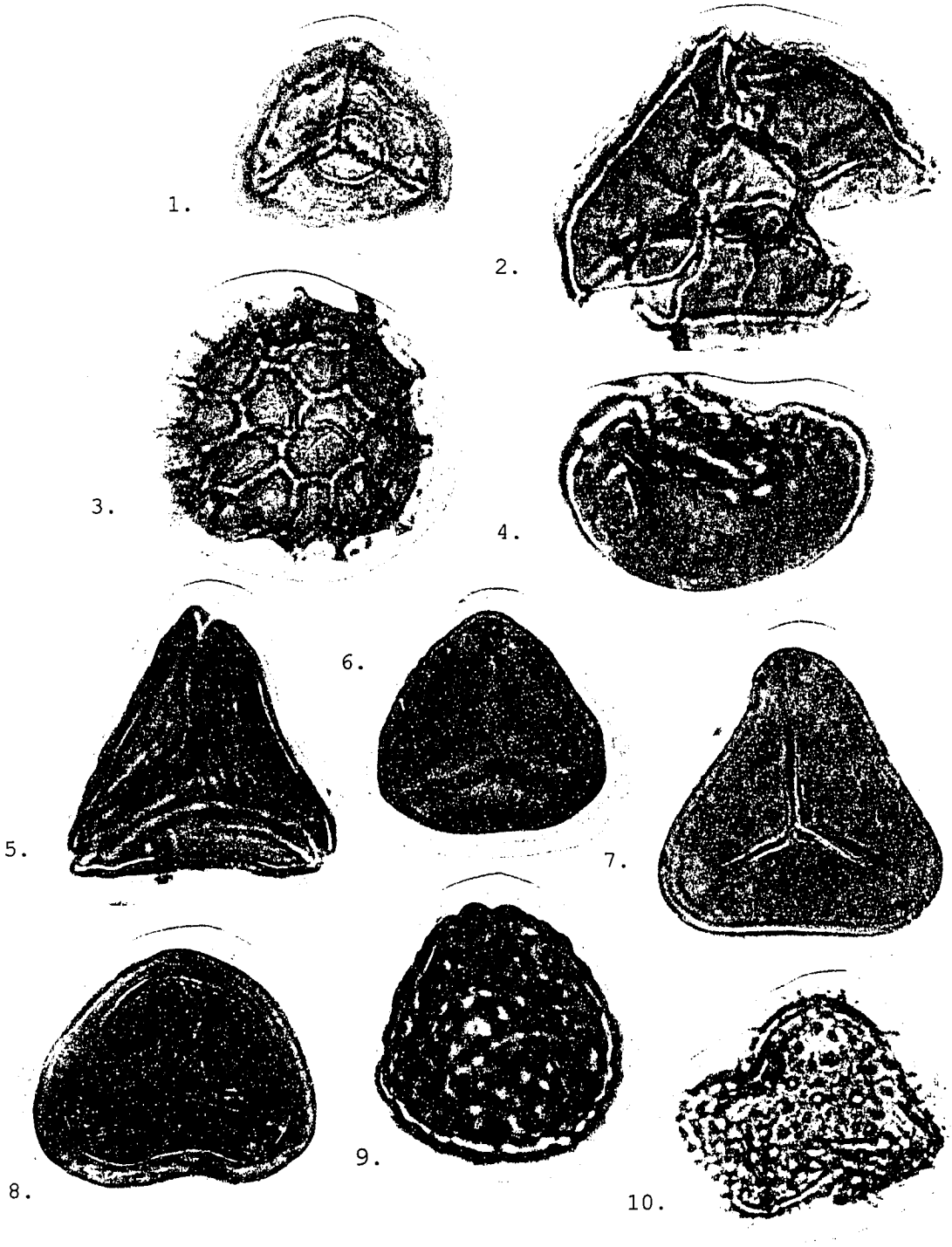


Plate 18

Mazuma Creek Palynoflora
Florule A-4

Slide No. 94SR (MZ) A004

1. *Camarazonosporites insignis* Norris 1967: R18-6, ↓, 31F

2. *Polycingulatisporites reduncus* (Bolkhovitina) Playford and Dettmann 1965: R18-5, ↓, 32U

3. *Triplanosporites sinuosus* (Pflug) Thompson and Pflug 1953: R18-24, ↑, 7M

4. *Cicatricosisporites* sp. cf. *C. hallei* (Cookson and Dettmann) Cookson and Dettmann 1959: R18-1, ↓, 37J

Plate 18

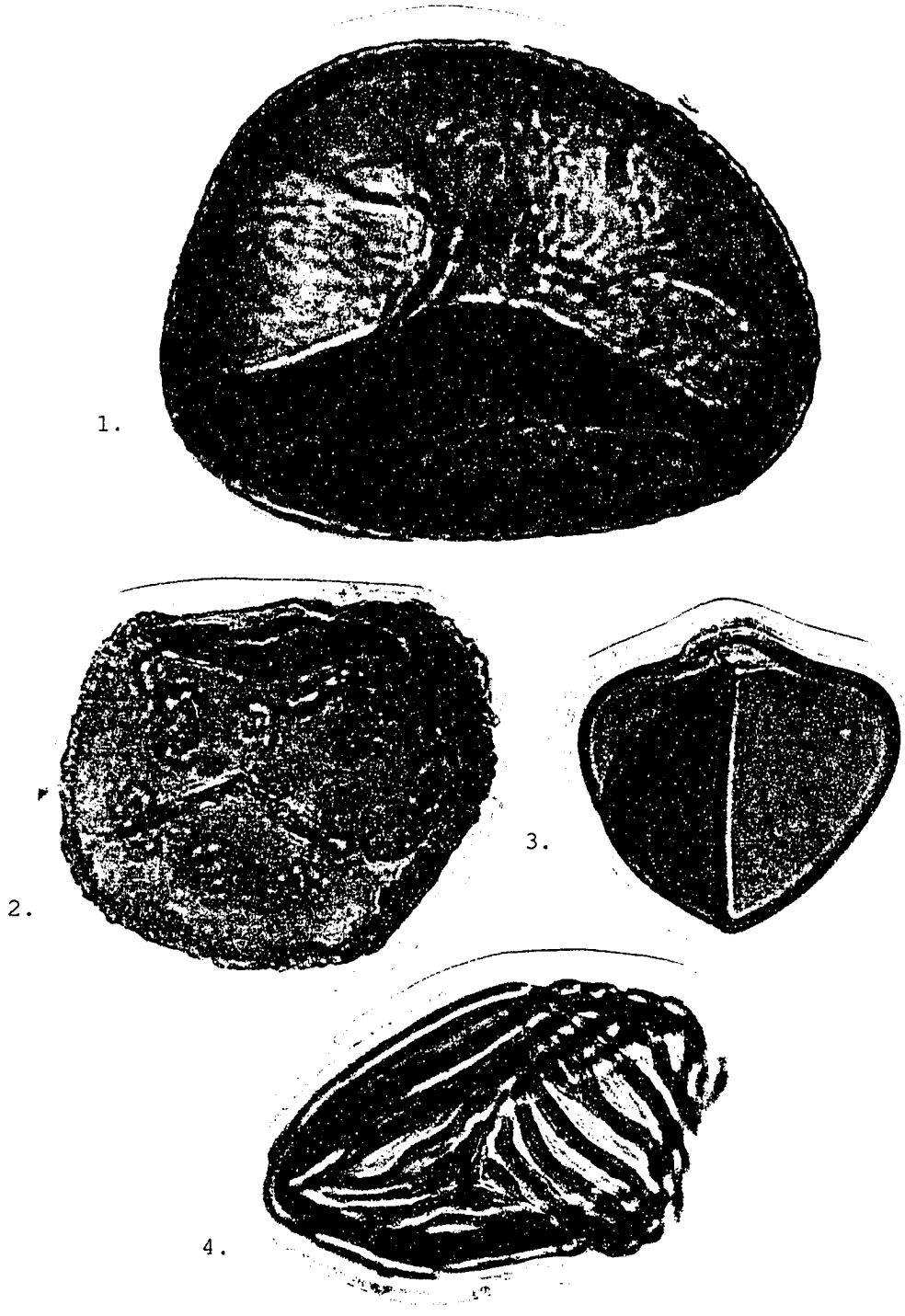


Plate 19

Mazuma Creek Palynoflora
Florule A-4

Slide No. 94SR (MZ) A004

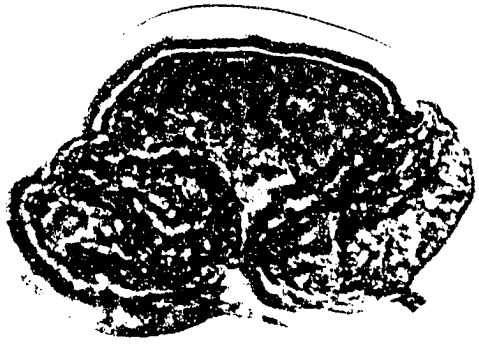
1. *Abiespollenites* sp.: R18-23, ↑, 3Q

2. *Alisporites grandis* (Cookson) Dettmann 1963: R18-25, ↑, 8F-G

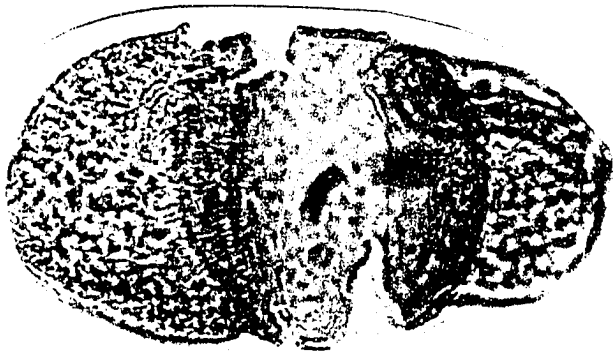
3. *Abiespollenites* sp.: R18-21, ↑, 3H

Plate 19

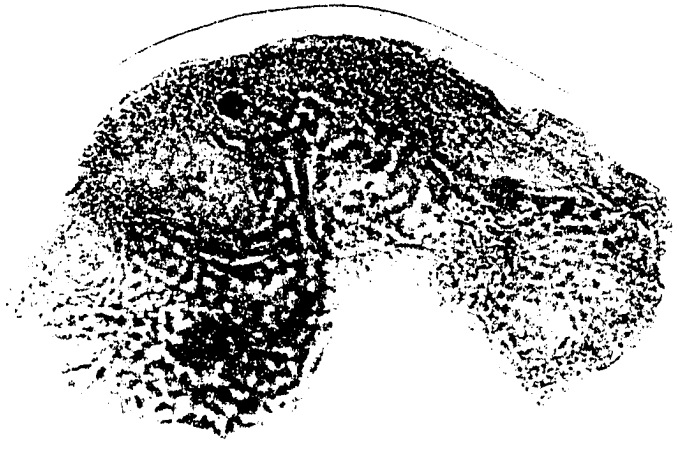
1.



2.



3.



25 µm

Plate 20

Mazuma Creek Palynoflora
Florule A-4

Slide No. 94SR (MZ) A004

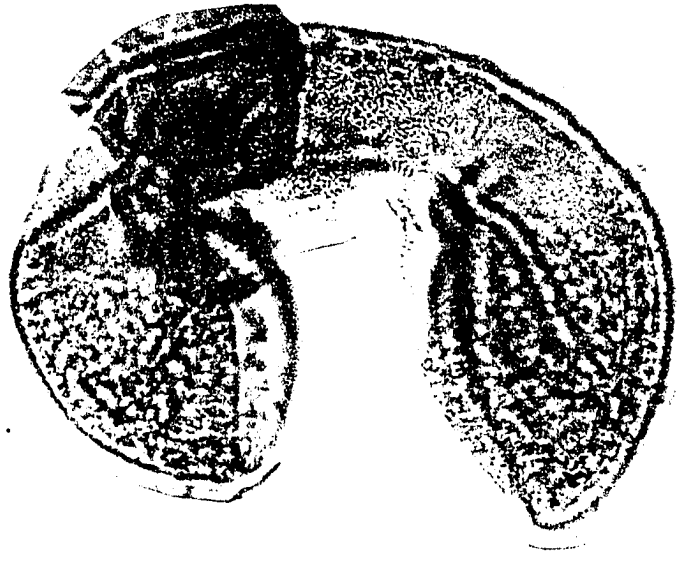
1. *Piceapollenites* sp.: R18-3, ↓, 35N

2. *Myrica* sp.: R18-22, ↑, 3Q

3. *Erdtmanipollis albertensis* Srivastava 1969: R18-32, ↑, 13N

Plate 20

1.



2.

3.

25 µm

Plate 21

Mazuma Creek Palynoflora
Florule A-4

Slide No. 94SR (MZ) A004

1. *Callistopollenites comis* Srivastava 1970: R18-7, ↓, 30X

2. *Rousea* sp.: R18-26, ↑, 8L

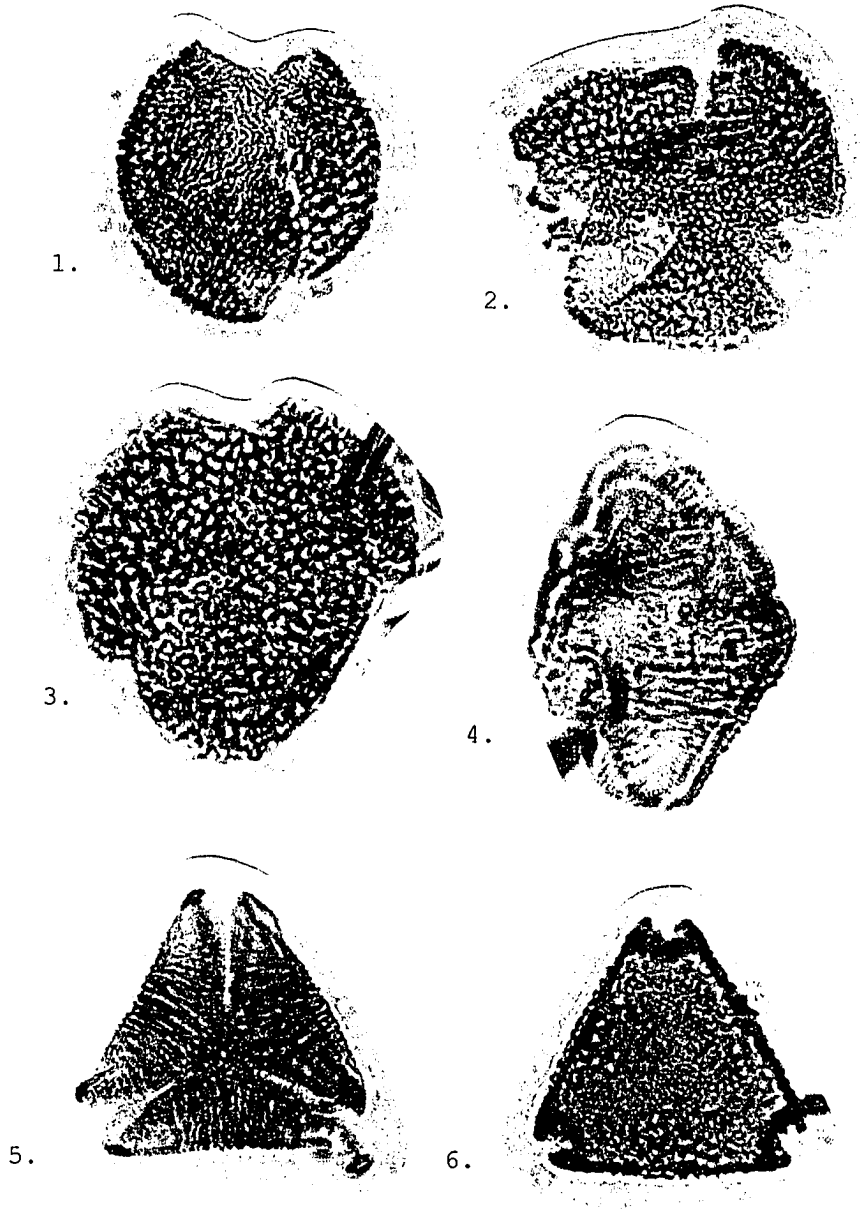
3. *Retitricolpites maximus* Singh 1971: R18-15, ↓, 21U-V

4. *Cranwellia rumseyensis* Srivastava 1966: R18-27, ↑, 9H

5. *C. rumseyensis*: R18-20, ↑, 1-2Q

6. *Proteacidites thalmanni* Anderson 1960: R18-8, ↓, 31K

Plate 21



25 µm

Plate 22

Mazuma Creek Palynoflora
Florule A-4

Slide No. 94SR (MZ) A004

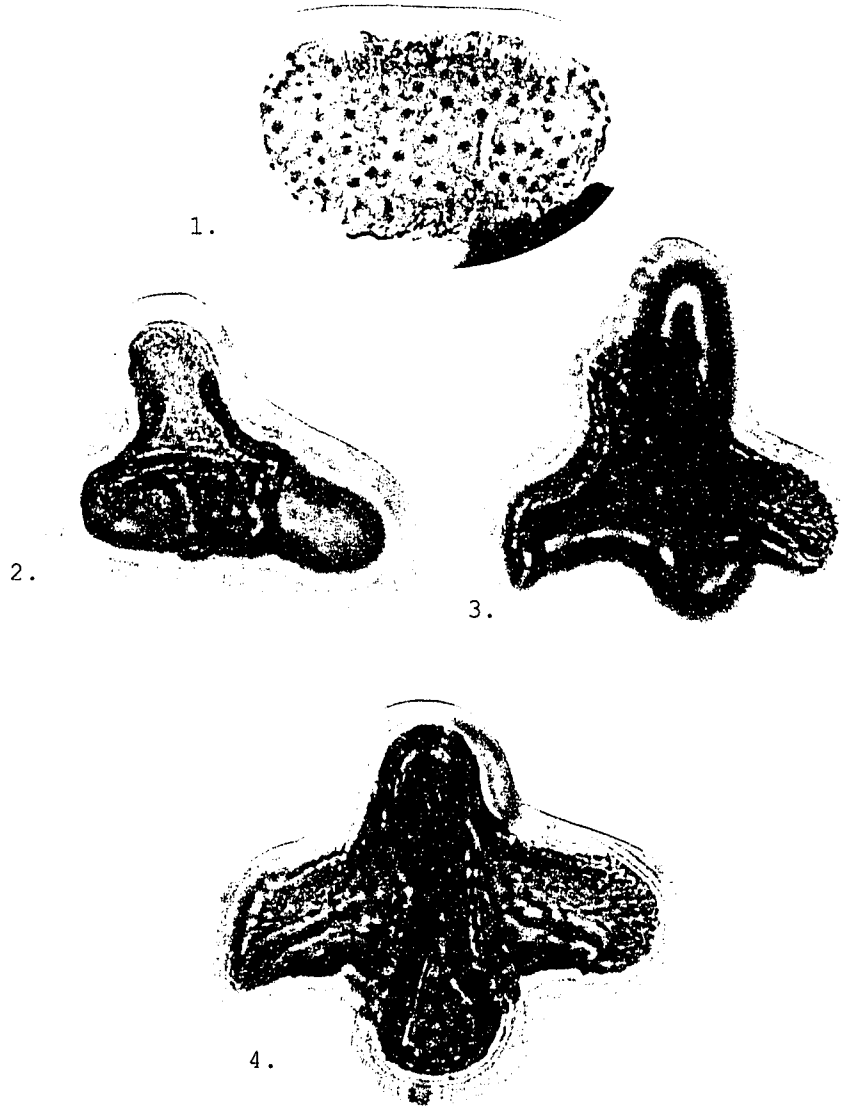
1. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: R18-14, ↓, 27Q

2. *Aquilapollenites* sp. cf. *A. delicatus* Stanley 1961: R18-19, ↓, 17M

3. *Aquilapollenites polaris* Funkhouser 1961: R18-18, ↓, 17G

4. *A. polaris*: R18-12/13, ↓, 28E

Plate 22



25 µm

Plate 23

Mazuma Creek Palynoflora
Florule A-5

Slide No. 94SR (MZ) A005

1. *Polypodiidites* sp.: R19-1, ↓, 34T

2. *Cyathidites australis* Couper 1953: R19-2, ↓, 34V

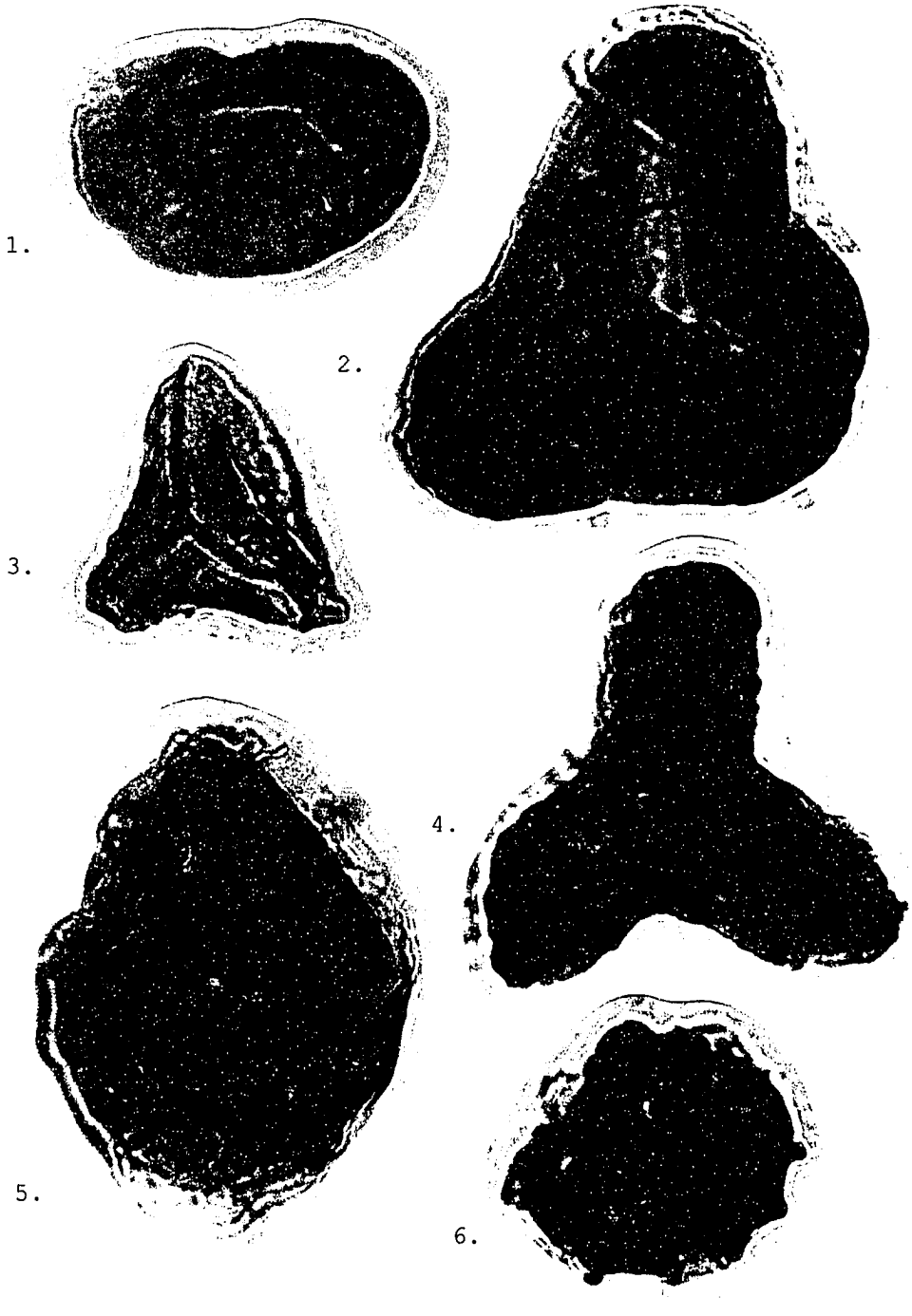
3. *Gleicheniidites circinidites* (Cookson) Brenner 1963: R19-27, ↑, 10R

4. *Concavissimisporites* sp.: R19-26, ↑, 8F

5. *Reticulatasporites dupliexinous* Brenner 1963: R19-19, ↓, 18P

6. *Retitriletes clavatoides* (Couper) Doring *et al.* 1963: R19-35, ↑, 15R

Plate 23



25 μm

Plate 24

Mazuma Creek Palynoflora
Florule A-5

Slide No. 94SR (MZ) A005

1. *Retitriletes subreticulaesporites* (Rouse) Krutzsch 1963: R19-22, ↑, 1L

2. *Retitriletes singhii* Srivastava 1972: R19-30, ↑, 12N

3. *Distaltriangulisporites perplexus* (Singh) Singh 1971: R19-18, ↓, 20P

4. *Camarozonosporites insignis* Norris 1967: R19-32, ↑, 14R

Plate 24

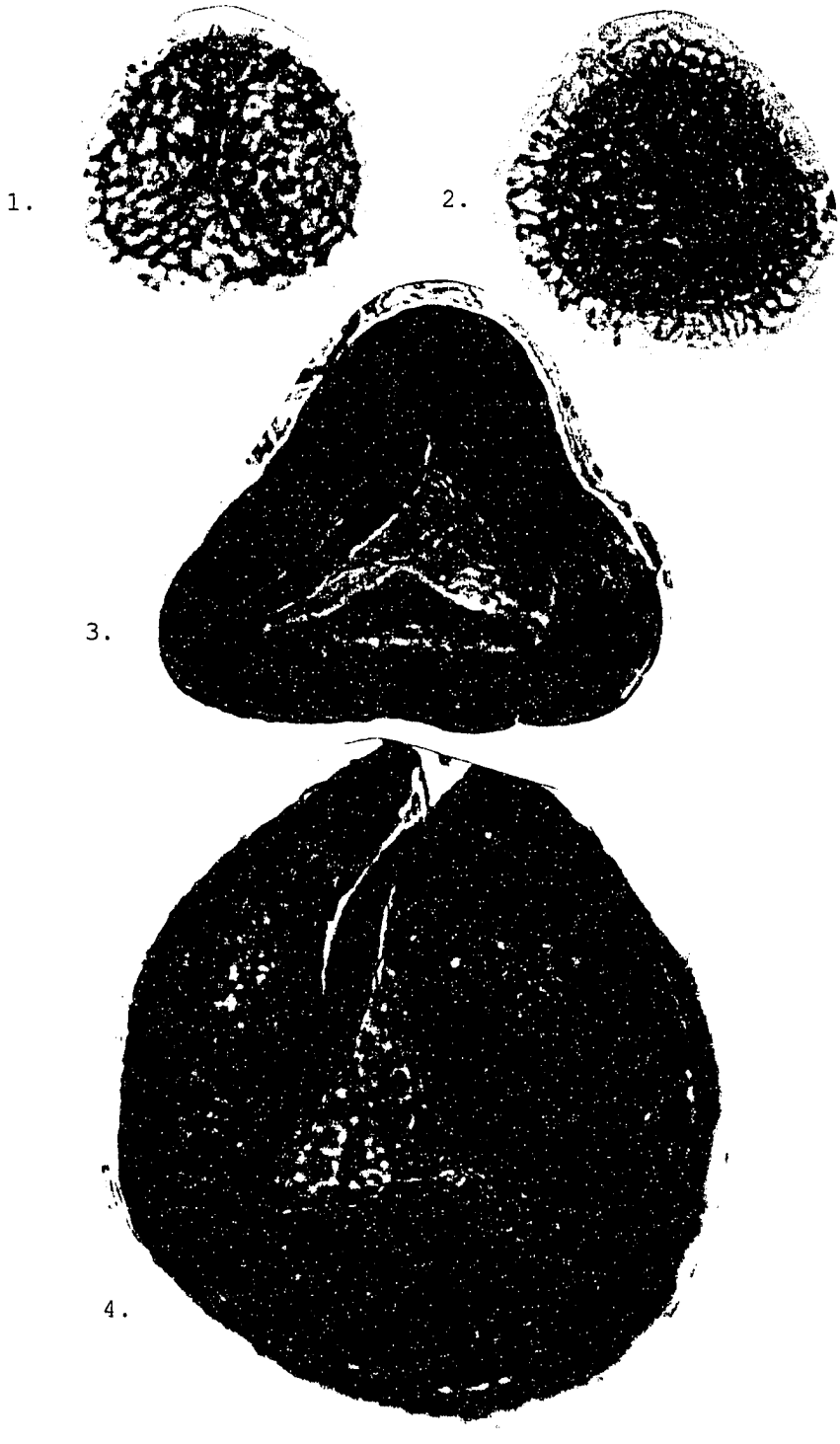


Plate 25

Mazuma Creek Palynoflora
Florule A-5

Slide No. 94SR (MZ) A005

1. *Cicatricosisporites sp.*: R19-28, ↑, 10G

2. *Cicatricosisporites* sp.: R19-4, ↓, 35K-L

3. *Cicatricosisporites imbricatus* (Markova) Singh 1971: R19-25, ↑, 9S

4. cf. *Anemia paradoxa* Bolkhovitina 1961: R19-33, ↑, 15E

5. *Cicatricosisporites* sp.: R19-12, ↓, 24C-D

Plate 25

25 µm

Plate 26

Mazuma Creek Palynoflora
Florule A-5

Slide No. 94SR (MZ) A005

1. *Cicatricosisporites radiatus* Krutzsch 1959: R19-9, ↓, 27E-F

2. *Microreticulatisporites* sp.: R19-8, ↓, 27E

3. *Schizaea reticulata* Cookson 1956: R19-5, ↓, 33-34H

Plate 26

Plate 27

Mazuma Creek Palynoflora
Florule A-5

Slide No. 94SR (MZ) A005

1. *Pityosporites constrictus* (Singh) Wingate 1980: R19-14, ↓, 20-21F

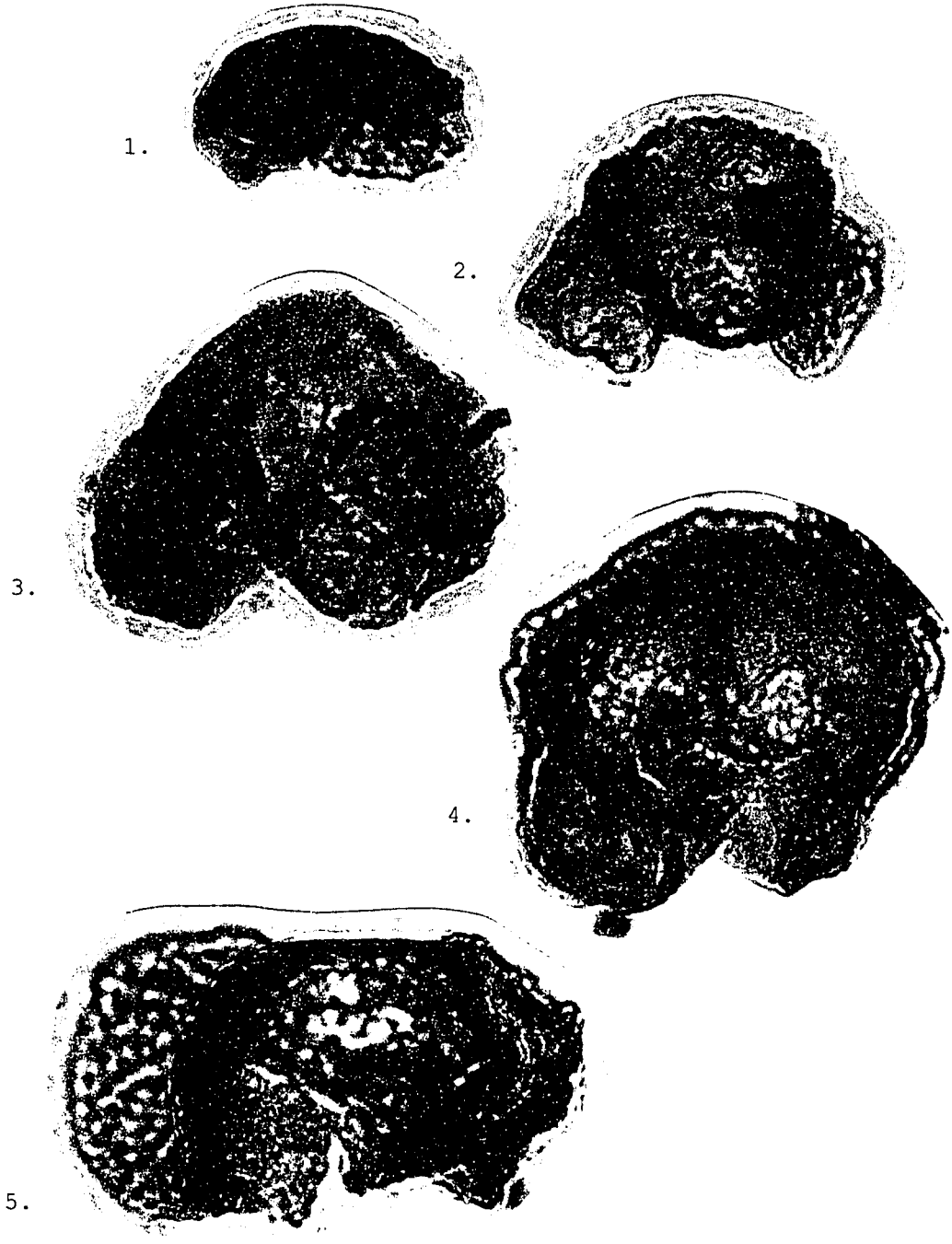
2. *Podocarpidites granulatis* Singh 1971: R19-10, ↓, 27M

3. *Abiespollenites* sp.: R19-3, ↓, 34T

4. *Abiespollenites* sp.: R19-15, ↓, 23J

5. *Podocarpidites* sp. cf. *radiatus* Brenner 1963: R19-24, ↑, 8V-W

Plate 27



25 µm

Plate 28

Mazuma Creek Palynoflora
Florule A-5

Slide No. 94SR (MZ) A005

1. *Podocarpidities* sp. cf. *P. ellipticus* Cookson 1947: R19-23, ↑, 1J

2. *Podocarpidities* sp. cf. *P. ellipticus* Cookson 1947: R19-29, ↑, 11Q

3. *Alisporites* sp. cf. *A. bilateralis* Rouse 1959: R19-11, ↓, 26S

4. *Pityosporites elongatus var. elongatus* Tschudy 1973: R19-13, ↓, 23N

Plate 28

Plate 29

Mazuma Creek Palynoflora
Florule A-5

Slide No. 94SR (MZ) A003

1. *Extraporopollenites* sp.: R19-34, ↑, 15Q

2. *Callistopollenites comis* Srivastava 1970: R19-31, ↑, 13L

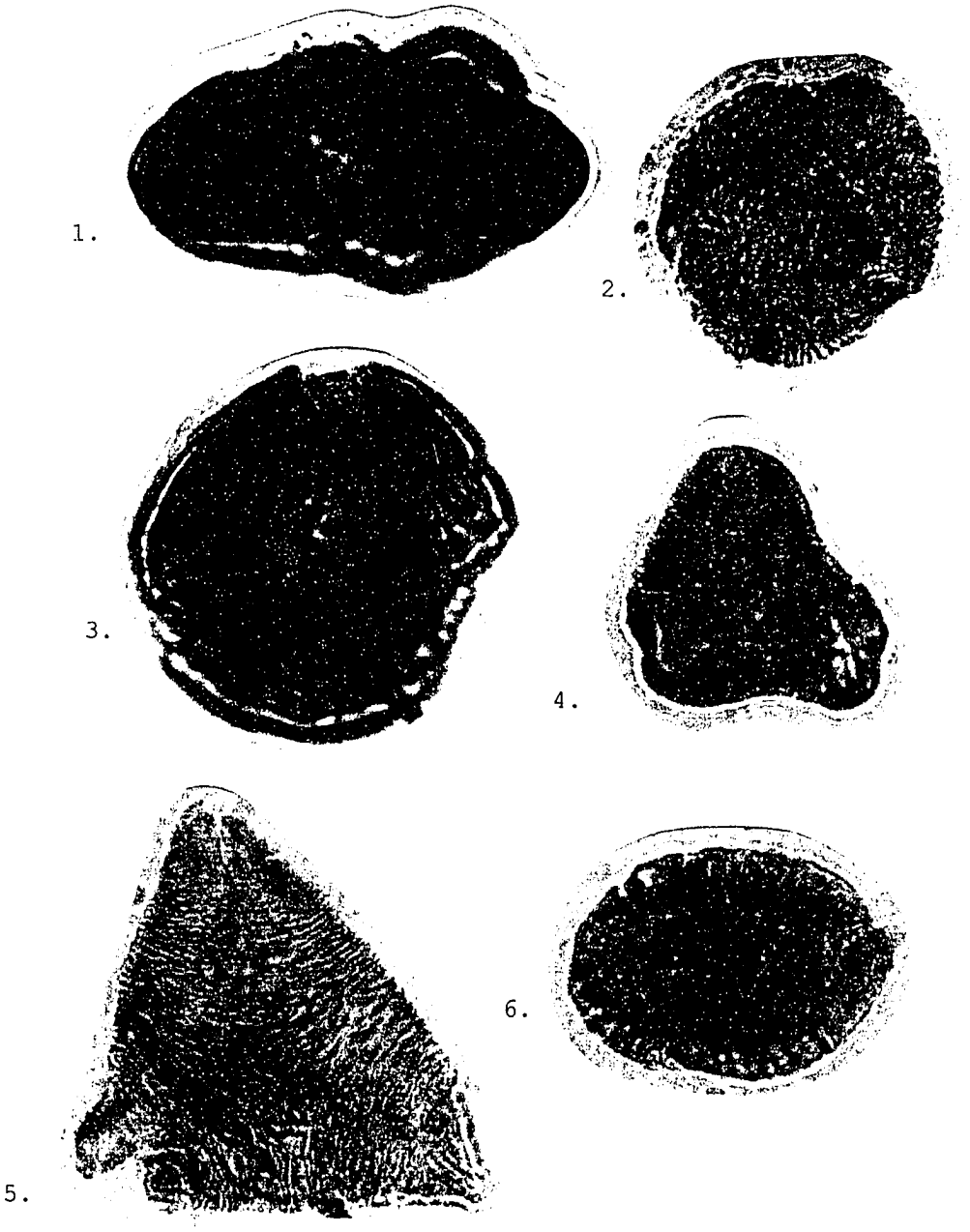
3. cf. *Quercus explanata* Anderson 1960: R19-6, ↓, 30W

4. cf. *Anacolosidities* sp.: R19-7, ↓, 28-29U

5. *Cranwellia striata* (Couper) Srivastava 1967: R19-20, ↓, 17-18J

6. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: R19-21, ↓, 17T

Plate 29



25 µm

APPENDIX B
Photographic Plates

Mazuma Creek Palynoflora
Plate 30
Florule B1-a, B1-b

Slide No. 94SR (MZ) B001-b

1. *Foveosporites* sp.: R11-18, ↓, 29R

2. *Distaltriangulisporites perplexus* (Singh) Singh 1971: R11-36, ↑, 15F

3. *Undulatisporites fossulatus* Singh 1971: R11-35, ↑, 12P

4. *Acanthotriletes varispinosus* Pocock 1962: R11-13, ↓, 35X

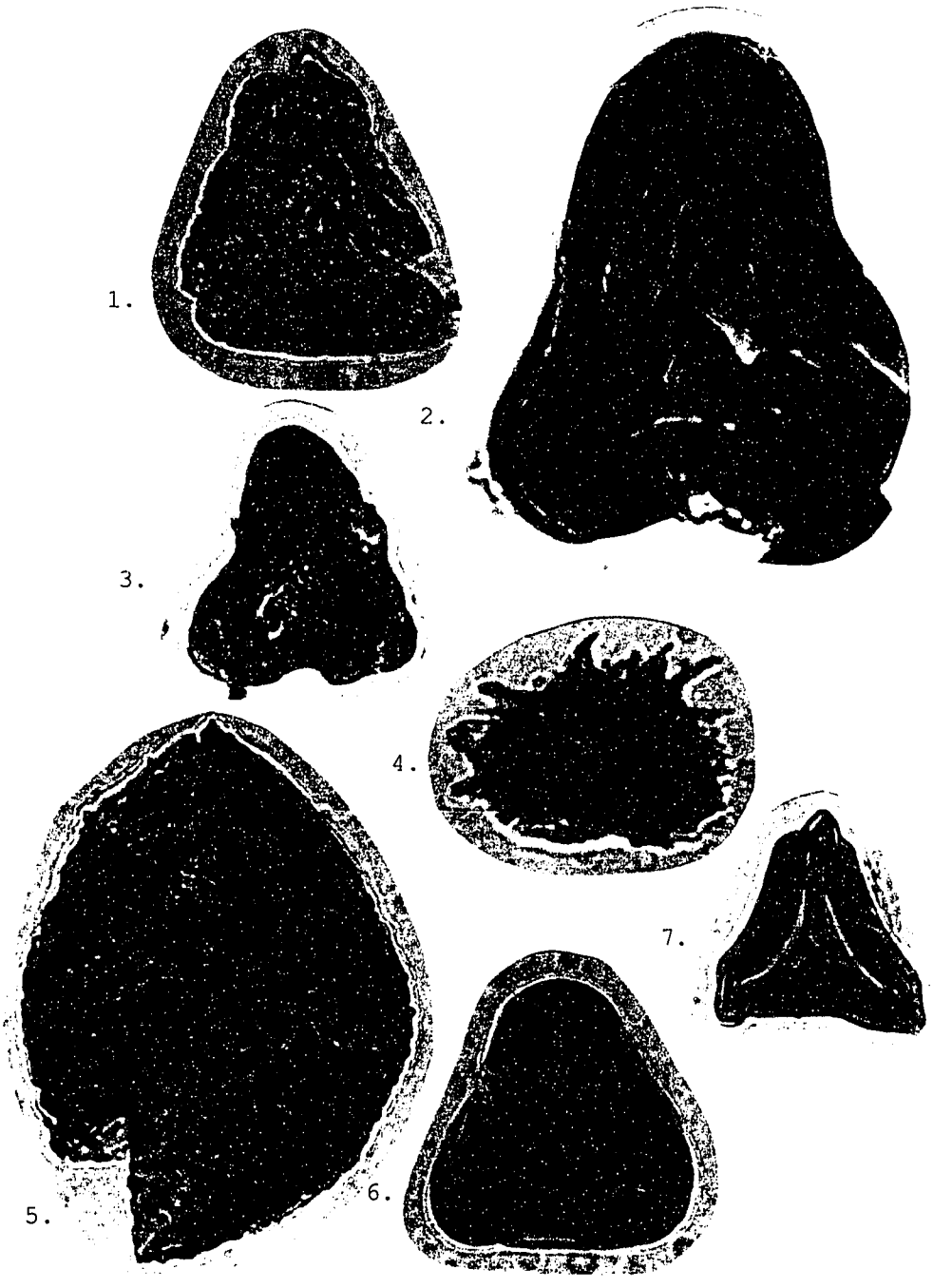
5. *Camarozonosporites insignis* Norris 1967: R11-12, ↓, 37H

6. *Cyathidites minor* Couper 1953: R11-20, ↓, 28L

Slide No. 94SR (MZ) B001-a

7. *Gleicheniidites concavisporites* (Rouse) Srivastava 1966: R20-35, ↓, 31-32U

Plate 30



25 µm

Plate 31

Mazuma Creek Palynoflora
Florule B1-b

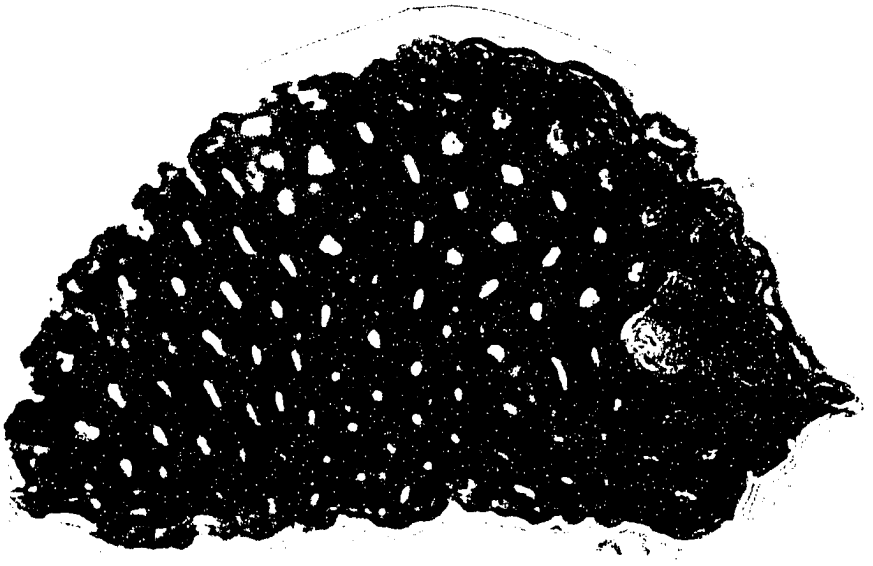
Slide No. 94SR (MZ) B001-b

1. *Schizea reticulata* Cookson 1956: R11-30, ↑, 4T

2. *Hamulatisporis amplus* Stanley 1965: R11-19, ↓, 29J

Plate 31

1.



2.

25 µm

Plate 32

Mazuma Creek Palynoflora
Florule B1-a, B1-b

Slide No. 94SR (MZ) B001-a

1. *Podocarpidites* sp. cf. *P. ellipticus* Cookson 1947: R20-36, ↓, 20-21V

Slide No. 94SR (MZ) B001-b

2. *Deltoidospora* sp.: R11-22, ↓, 12G

3. *Deltoidospora neddeni* (Potonié) Orbell 1973: R11-28, ↑, 3E

4. *Spermatites* sp.: R11-29, ↑, 3J

5. *Proteacidites thalmanni* Anderson 1960: R11-37, ↓, 25F

6. *Scollardia trapaformis* Srivastava 1966: R11-31, ↑, 5V

7. *Aquilapollenites delicatus* Stanley 1961: R11-27, ↑, 1E

8. *Mancicorpus pulcher* (Funkhouser) Srivastava 1972: R11-14, ↓, 33S

Plate 32

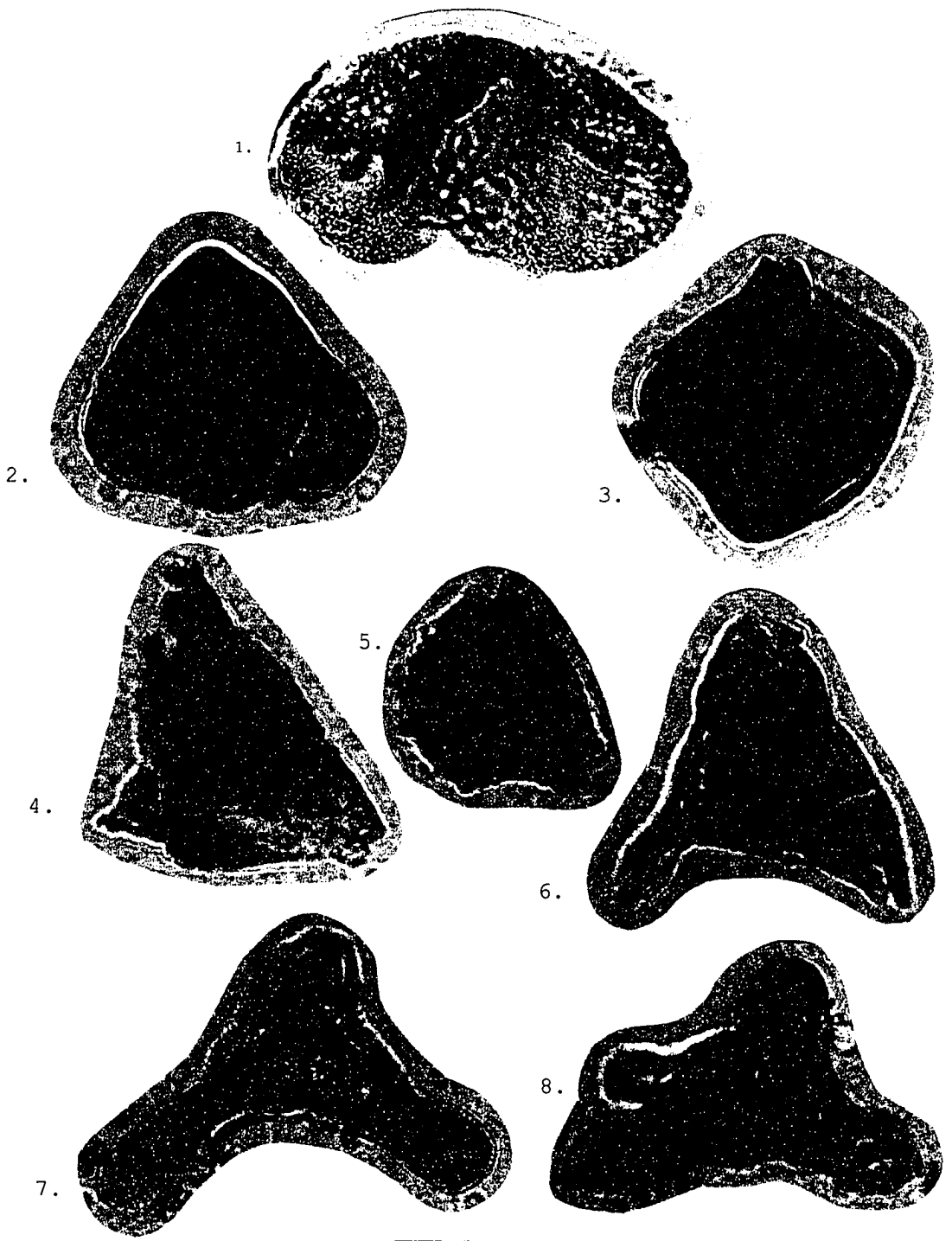


Plate 33

Mazuma Creek Palynoflora
Florules B-2, B-3

Slide No. 94SR (MZ) B002

1. *Polypodiidites* sp.: R12-27, ↓, 22U

Slide No. 94SR (MZ) B003

2. *Lycopodiumsporites* sp.: R12-4, ↑, 3K

Slide No. 94SR (MZ) B002

3. *Lycopodiumsporites singhii* Srivastava: R12-23, ↓, 25K

4. *Cingutriletes clavus* (Balme) Dettmann 1963: R12-14, ↓, 33G

5. *Stereisporites antiquasporites* (Wilson and Webster) Dettman 1963: R11-4, ↑, 13S

6. *Retitriletes austroclavatidites* (Cookson) Krutzsch 1963: R11-10, ↑, 17Q

Plate 33

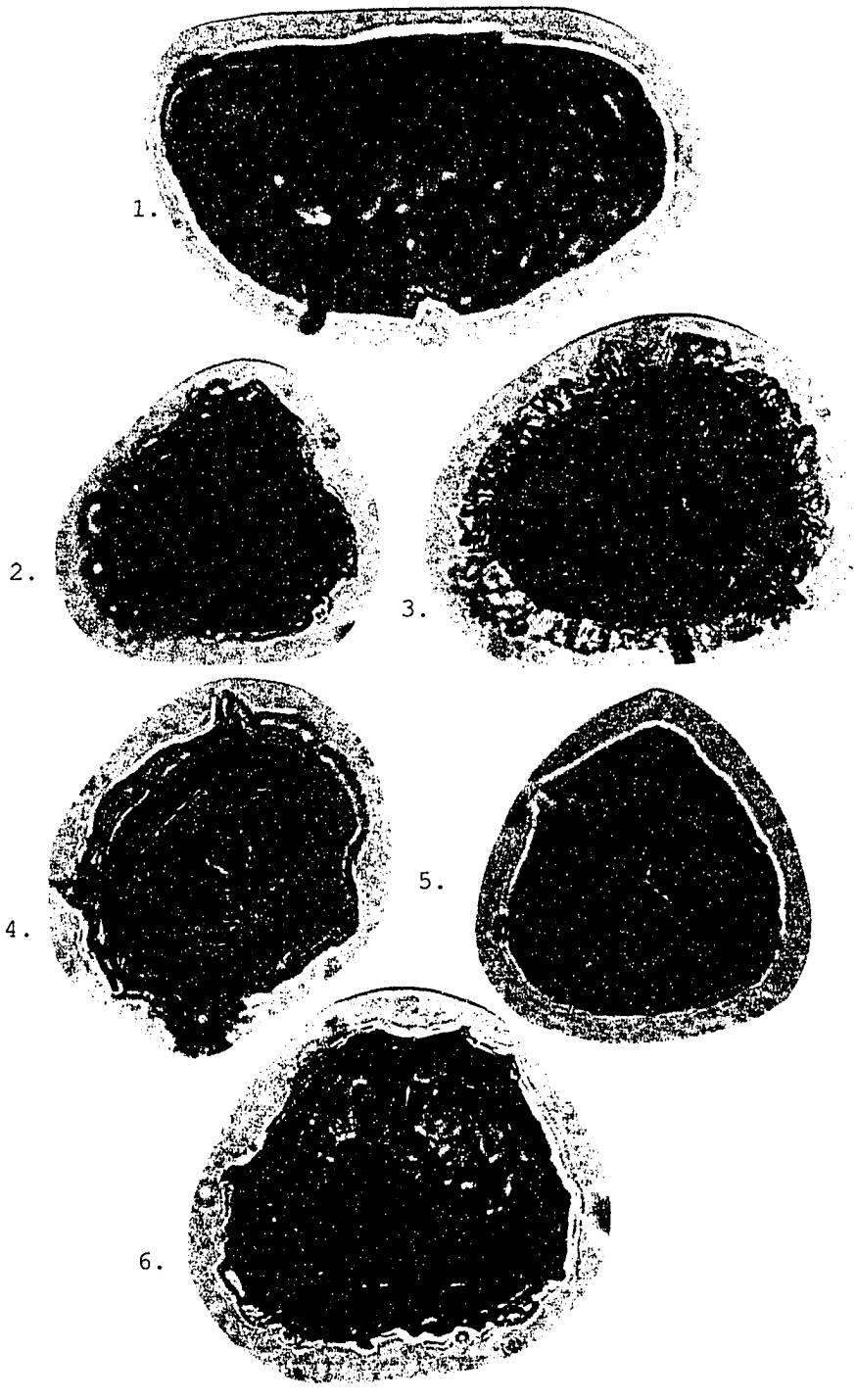


Plate 34

Mazuma Creek Palynoflora
Florules B-2, B-3

Slide No. 94SR (MZ) B002

1. *Gleicheniidites umbonatus* (Bolkhovitina) Bolkhovitina 1968: R12-29, ↓, 21Q

2. *Camarozonosporites* sp.: R12-31, ↓, 19U

3. *Lygodioisporites verrucosus* Srivastava 1967: R11-8, ↑, 17J

Slide No.94SR (MZ) B003

4. *Deltoidospora neddeni* (Potonié) Orbell 1973: R12-8, ↑, 10-11Q

Slide No. 94SR (MZ) B002

5. *Taurocusporites segmentatus* Stover 1962: R11-3, ↑, 11G

Plate 34

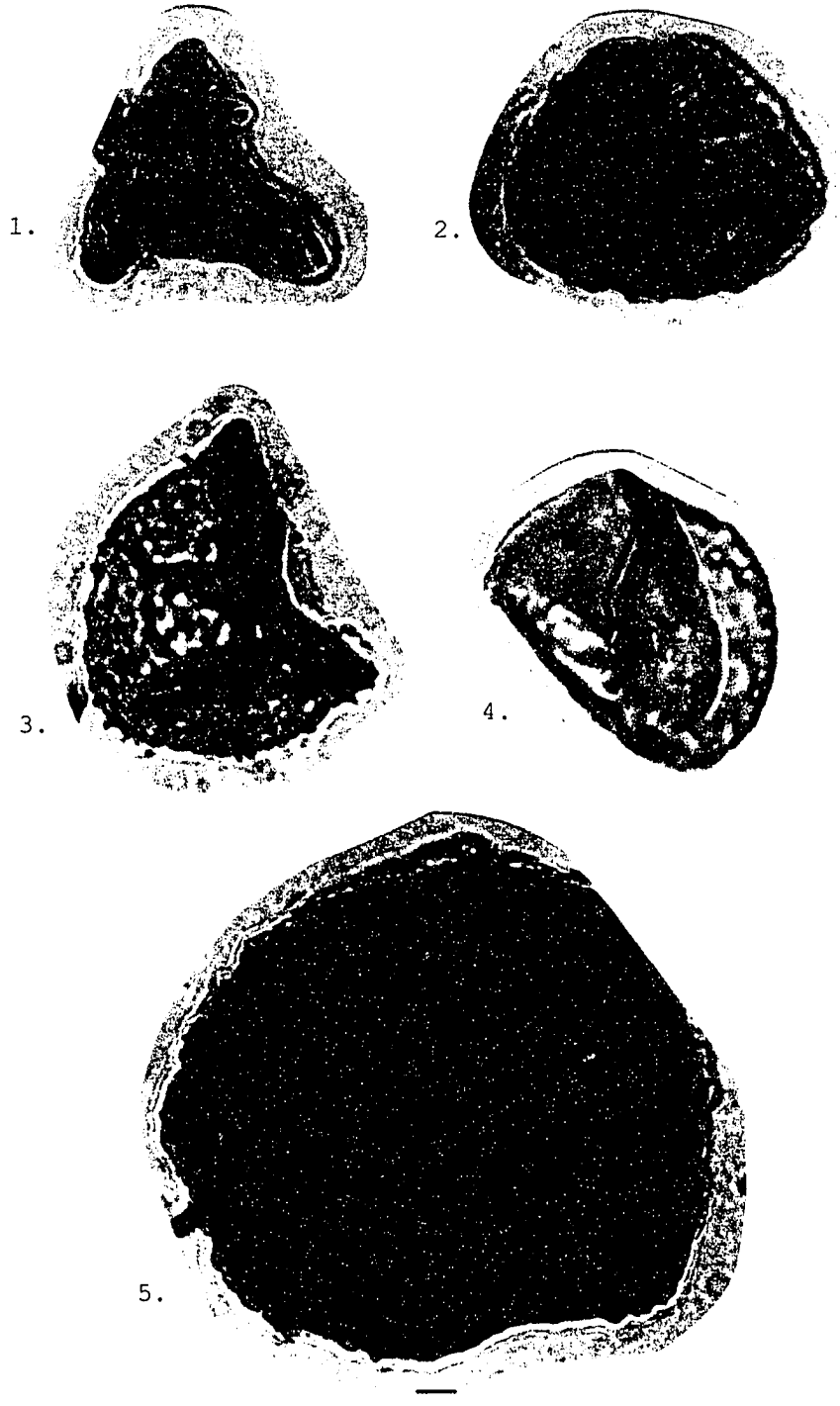


Plate 35

Mazuma Creek Palynoflora
Florules B-2, B-3

Slide No. 94SR (MZ) B003

1. *Cyathidites minor* Couper 1953: R12-10, ↑, 12E

Slide No. 94SR (MZ) B002

2. *Deltoidospora psilostoma* Rouse 1959: R12-20, ↓, 26N-P

3. *Dictyophyllidites mortonii* (de Jersey) Playford and Dettmann 1965: R12-34, ↑, 1Y

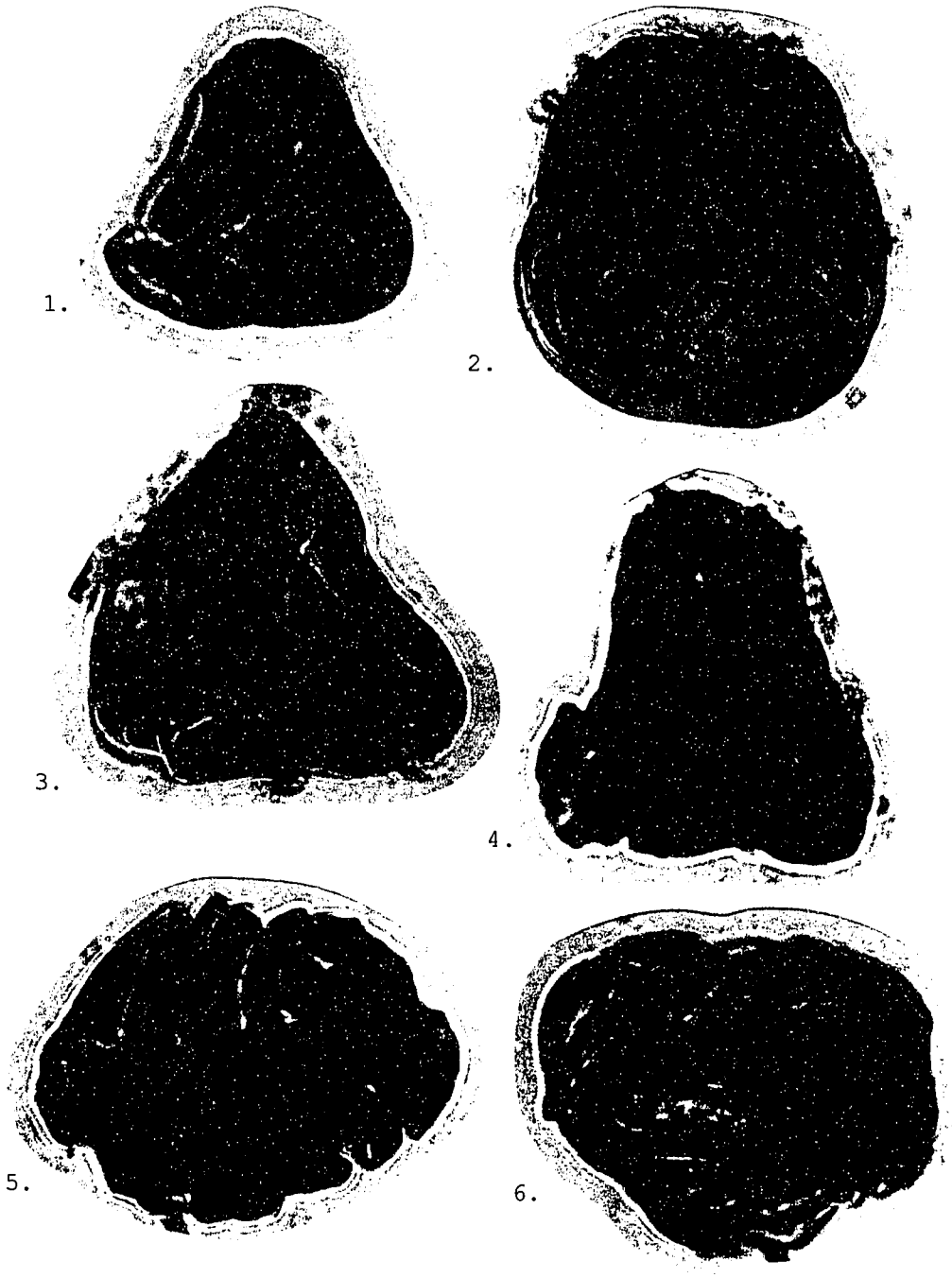
4. Unknown genus: R12-36, ↑, 3P

5. *Cicatricosisporites* sp.: R11-5, ↑, 13C

Slide No. 94SR (MZ) B003

6. *Cicatricosisporites annulatus* Archangelsky and Gamerro 1966: R12-9, ↑, 12-13F

Plate 35



25 µm

Plate 36

Mazuma Creek Palynoflora
Florule B-2

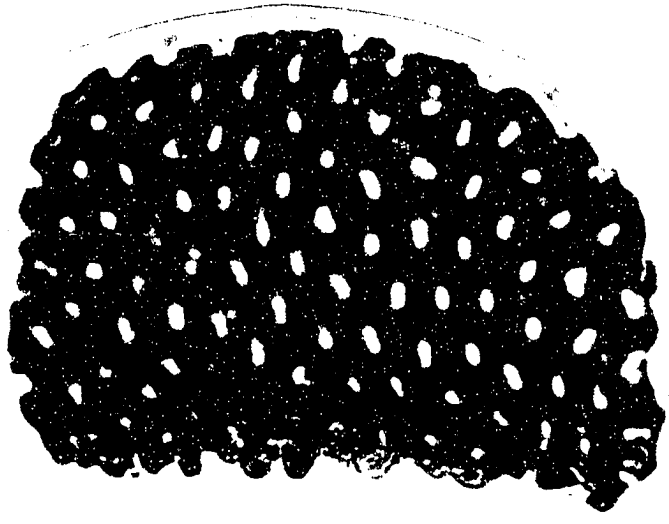
Slide No. 94SR (MZ) B002

1. *Schizea reticulata* Cookson 1956: R12-35, ↑, 2G

2. *Lycopodiacidites caperatus* Singh 1971: R12-32, ↓, 17T

Plate 36

1.



2.

25 µm

Plate 37

Mazuma Creek Palynoflora
Florules B-2

Slide No. 94SR (MZ) B002

1. *Vitreisporites pallidus* (Reissinger) Nilsson 1958: R12-16, ↓, 28–29Y

2. *Podocarpidites granulatus* Singh 1971: R12-37, ↑, 6H

3. *Abiespollenites* sp.: R11-2, ↑, 10T-U

4. *Extraporopollenites* sp.: R12-26, ↓, 22V

5. *Ephedrapites* sp.: R11-1, ↑, 9G

6. *Spermatites* sp.: R12-7, ↑, 7-8L

Plate 37

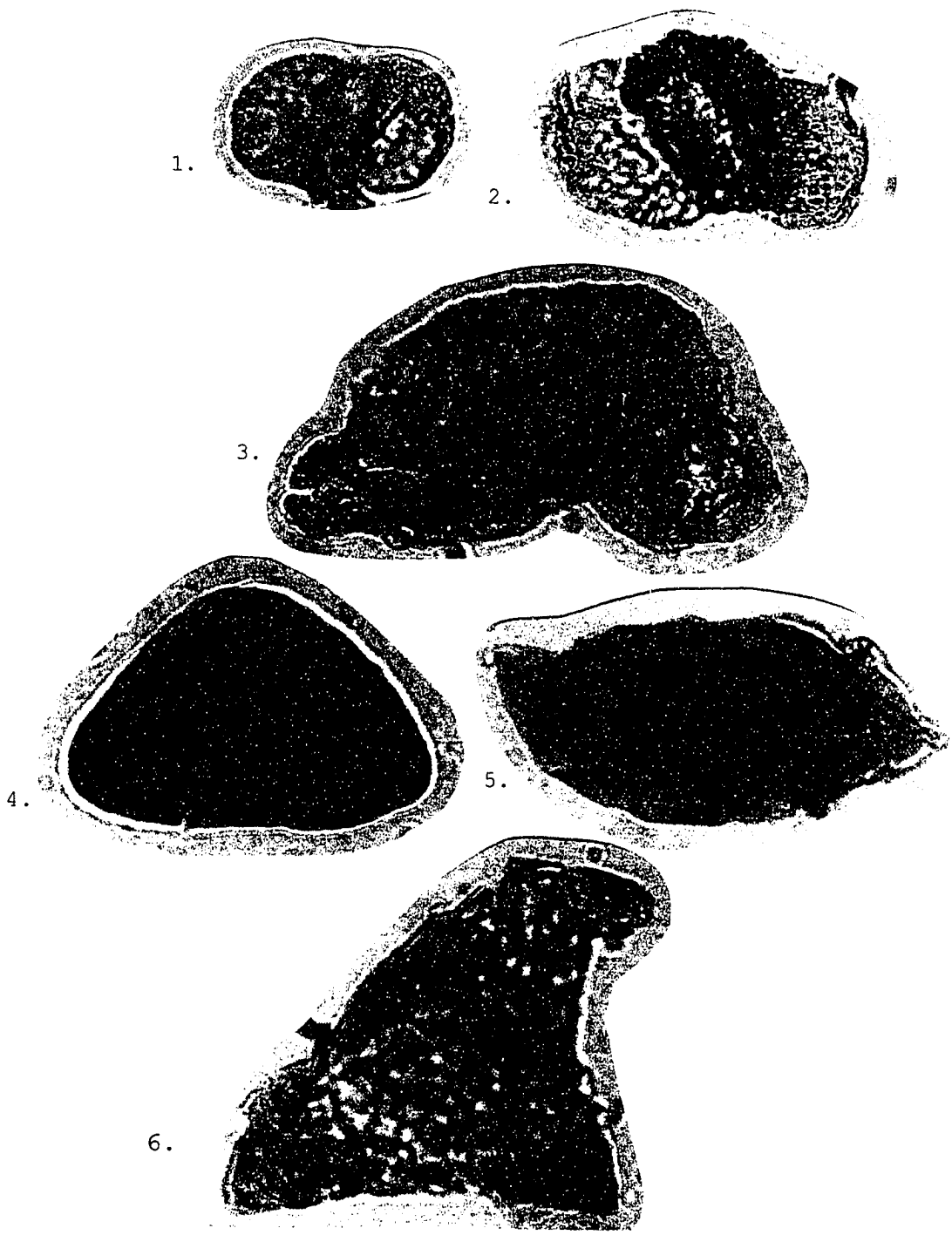


Plate 38

Mazuma Creek Palynoflora
Florule B-2

Slide No. 94SR (MZ) B002

1. Unknown genus: R12-30, ↓, 20T

2. cf. *Tetrasporina* sp.: R12-19, ↓, 26N

3. *Rousea subtilis* Srivastava 1970: R12-25, ↓, 22V

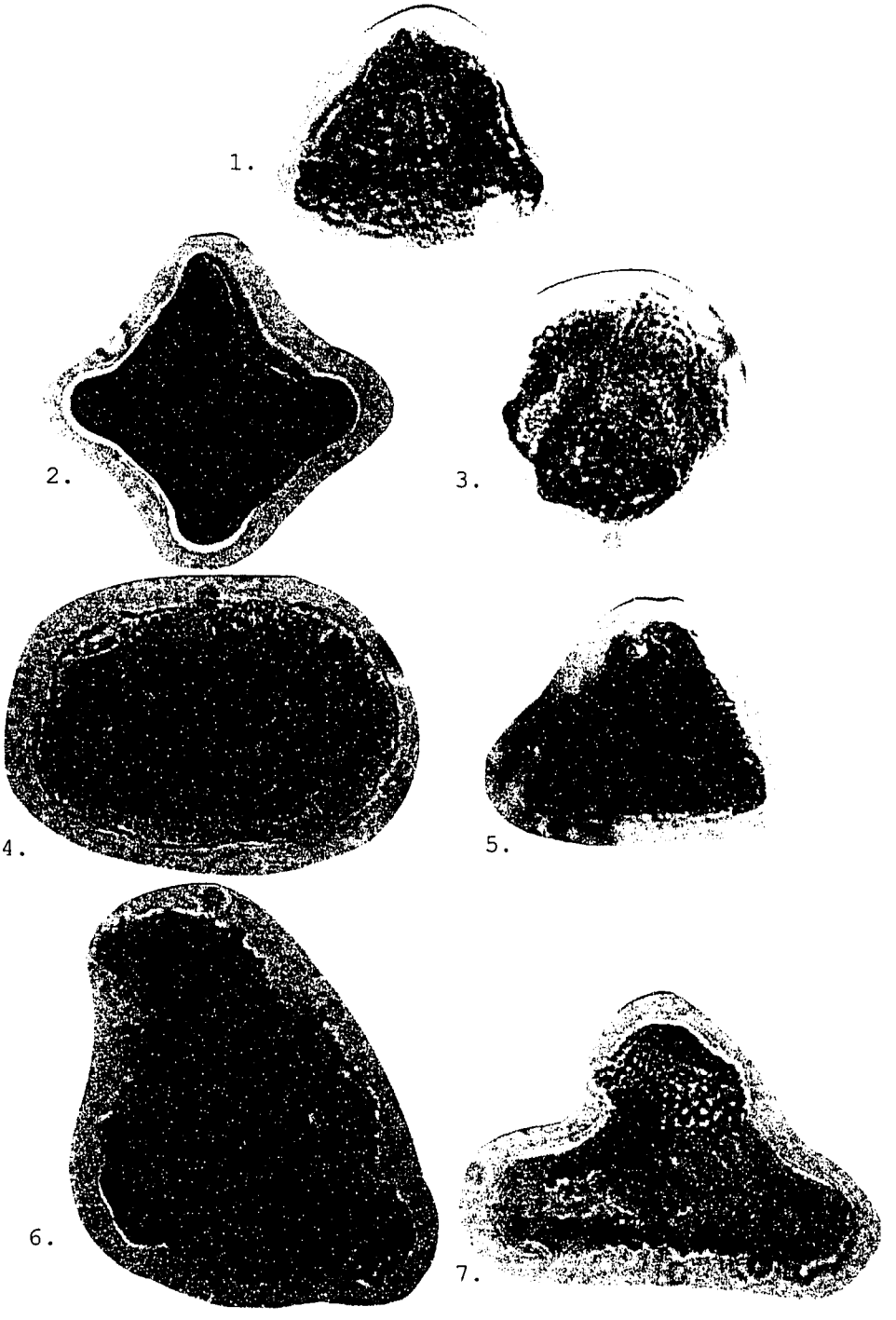
4. *Wodehouseia gracile* (Samoilovich) Podrovaskaya 1966: R11-7, ↑, 14L

5. *Cranwellia striata* (Couper) Srivastava 1967: R12-18, ↓, 26M

6. *Penetetrapites inconspicuus* Sweet 1986: R11-9, ↑, 17W

7. *Aquilapollenites senonicus* (Mchedlishvili) Tschudy and Leopold 1969: R12-21, ↓, 26E

Plate 38



25 µm

Plate 39

Mazuma Creek Palynoflora
Florule B-4

Slide No. 94SR (MZ) B004

1. *Laevigatosporites gracilis* Wilson and Webster 1946: R20- 19, ↓, 31M

2. *Cyathidites australis* Couper 1953: R20-20, ↓, 20U-V

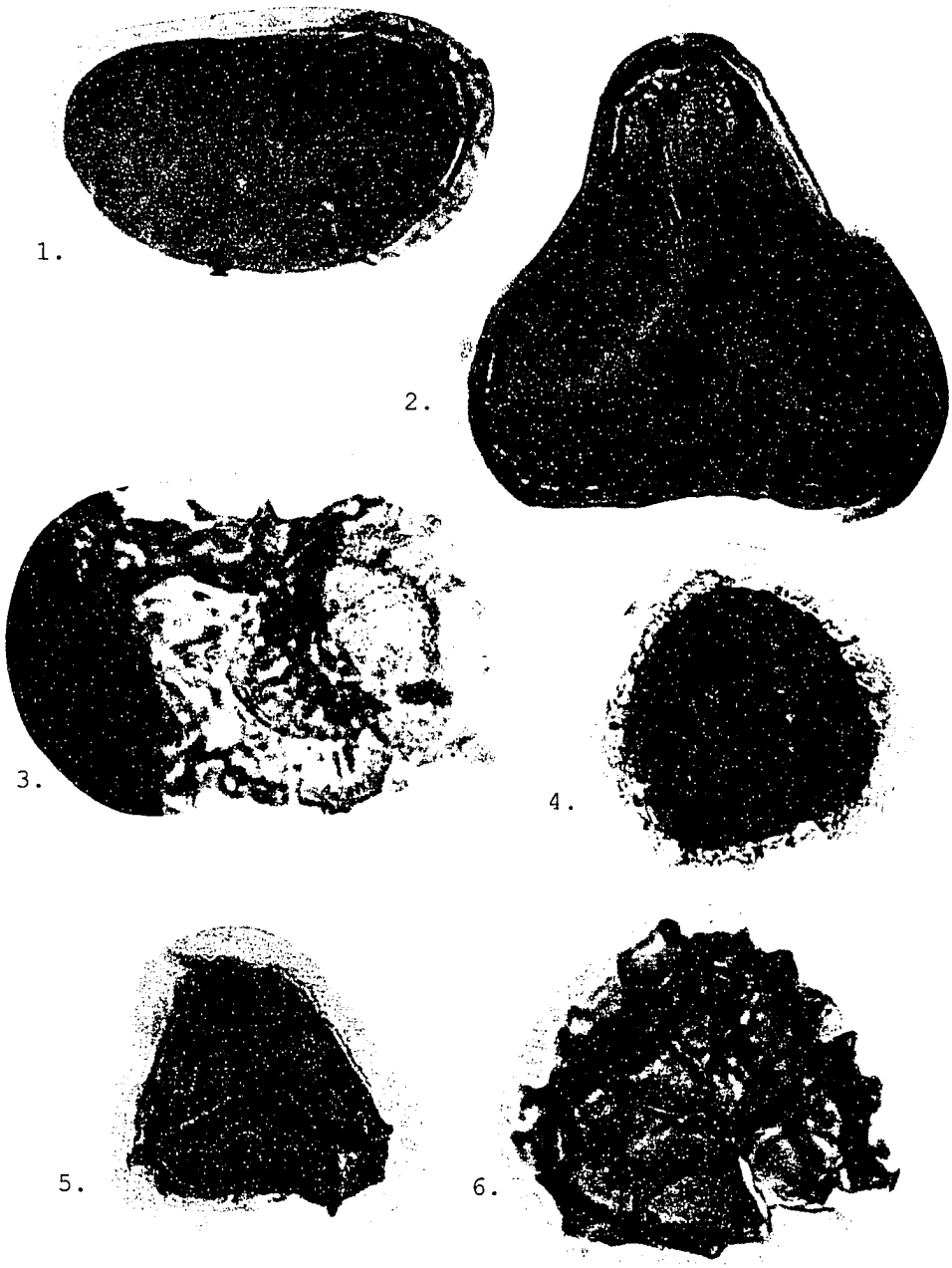
3. *Ceratosporites* sp. cf. *C. couliensis* Srivastava 1972: R20-9, ↑, 3J

4. *Lycopodiumsporites* sp.: R20-11, ↑, 11-12F

5. *Retitriletes clavatoides* (Couper) Doring *et al.* 1963: R20-13, ↑, 8-9L

6. *Lycopodiumsporites crassimacerius* Hedlund 1966: R20-22, ↓, 36U

Plate 39



25 μm

Plate 40

Mazuma Creek Palynoflora
Florule B-4

Slide No. 94SR (MZ) B004

1. *Leptolepidites verrucatus* Couper 1953: R20-30, ↓, 26U

2. *Cicatricosisporites* sp.: R20-14, ↑, 8-9H

3. *Camarozonosporites insignis* Norris 1967: R20-23, ↓, 34J

4. *Schizea reticulata* Cookson 1956: R20-8, ↓, 17D

Plate 40

Plate 41

Mazuma Creek Palynoflora
Florule B4

Slide No. 94SR (MZ) B004

1. *Lycopodiacidites caperatus* Singh 1971: R20-29, ↓, 26-27N

2. *Ceratosporites levidensis* (Balme) Burden and Hills 1989: R20-18, ↓, 31F

3. *Gleicheniidites circinidites* (Cookson) Brenner 1963: R20-26, ↓, 27L

4. *Gleicheniidites concavisporites* (Rouse) Srivastava 1966: R20-28, ↓, 26-27Q

5. *Foveosporites* sp.: R20-27, ↓, 27U-V

6. *Distaltriangulatisporites perplexus* (Singh) Singh 1971: R20-16, ↓, 11-12L

Plate 41

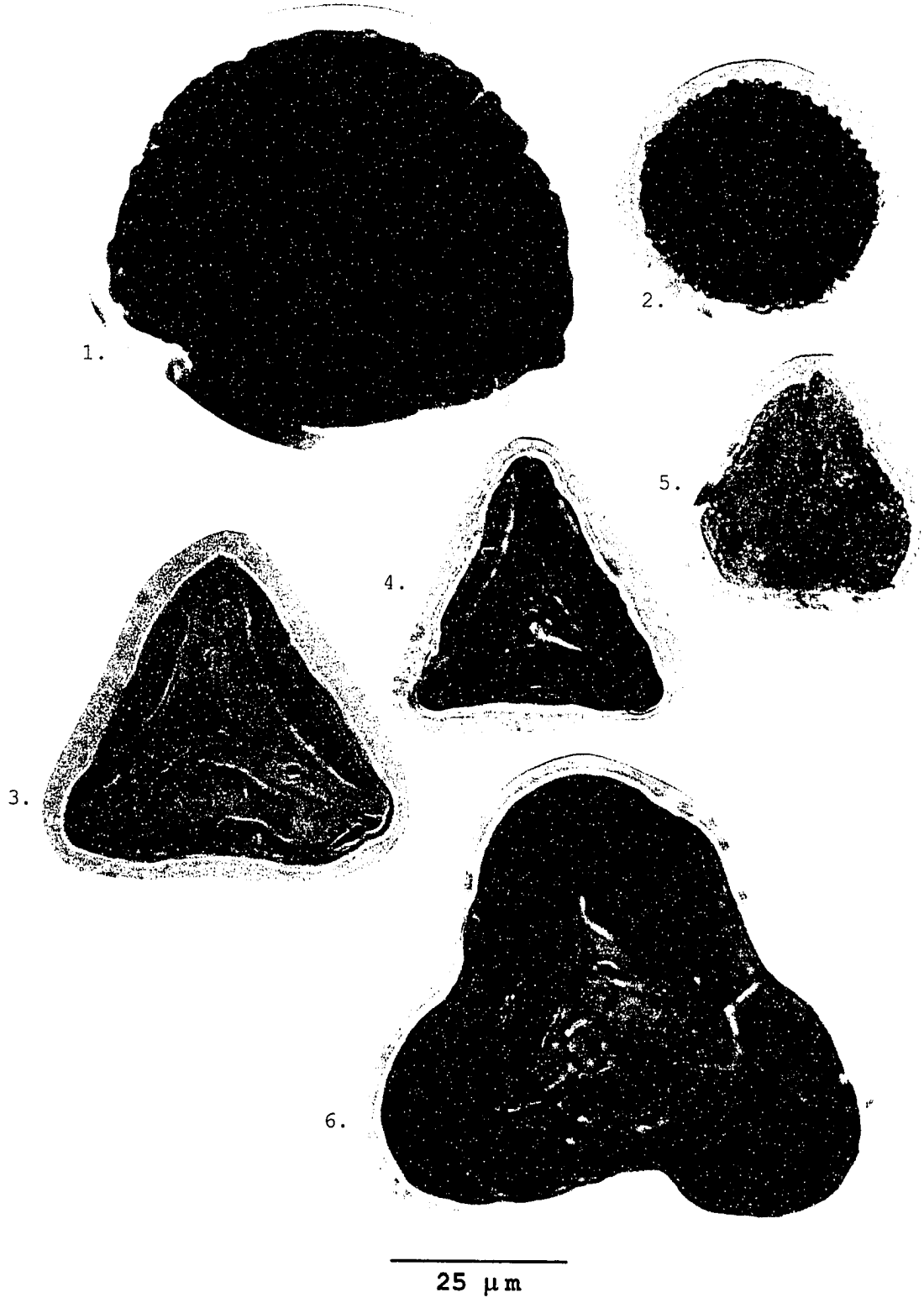


Plate 42

Mazuma Creek Palynoflora
Florule B-4

Slide No. 94SR (MZ) B004

1. *Cycadopites reticulatus* ((Nilsson) Cornet and Traverse 1975: R20-25, ↓, 32-33J

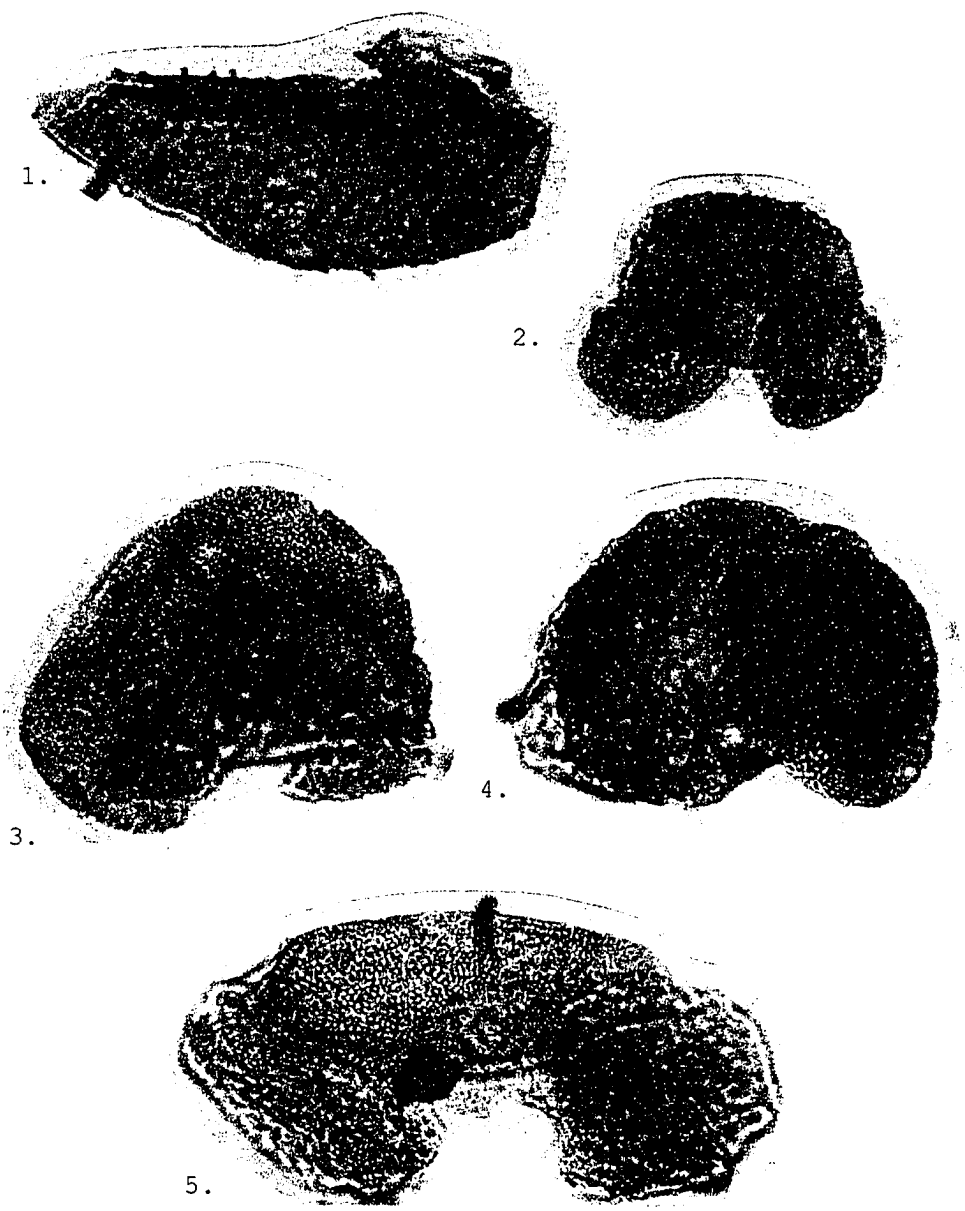
2. *Podocarpidites granulatus* Singh 1971: R20-12, ↑, 12P

3. *Abiespollenites* sp.: R20-10, ↑, 14-15P

4. *Podocarpidites* sp.: R20-17, ↑, 11T

5. *Abietipites* sp.: R20-7, ↓, 19Q

Plate 42



25 μm

Plate 43

Mazuma Creek Palynoflora
Florule B-4

Slide No. 94SR (MZ) B004

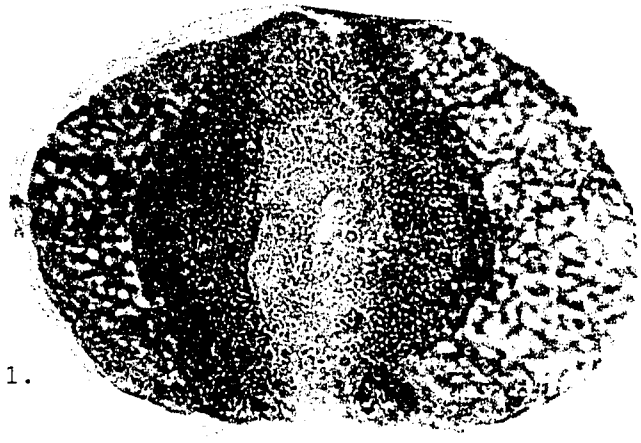
1. *Alisporites grandis* (Cookson) Dettmann 1963: R20-33, ↓, 15K

2. *Podocarpidites* sp.: R20-31, ↓, 25L-M

3. *Retitricolpites vulgaris* Pierce 1961: R20-21, ↓, 36S

4. *Trudopollis pertrudens* (Pflug in Thompson and Pflug 1953a) Pflug 1953: R20-32, ↓, 22M

Plate 43



1.

2.

3.

4.

25 µm

Plate 44

Mazuma Creek Palynoflora
Florule B-5

Slide No. 94SR (MZ) B005

1. Wood: R22-30, ↓, 34T

2. Wood: R21-15, ↑, 16M

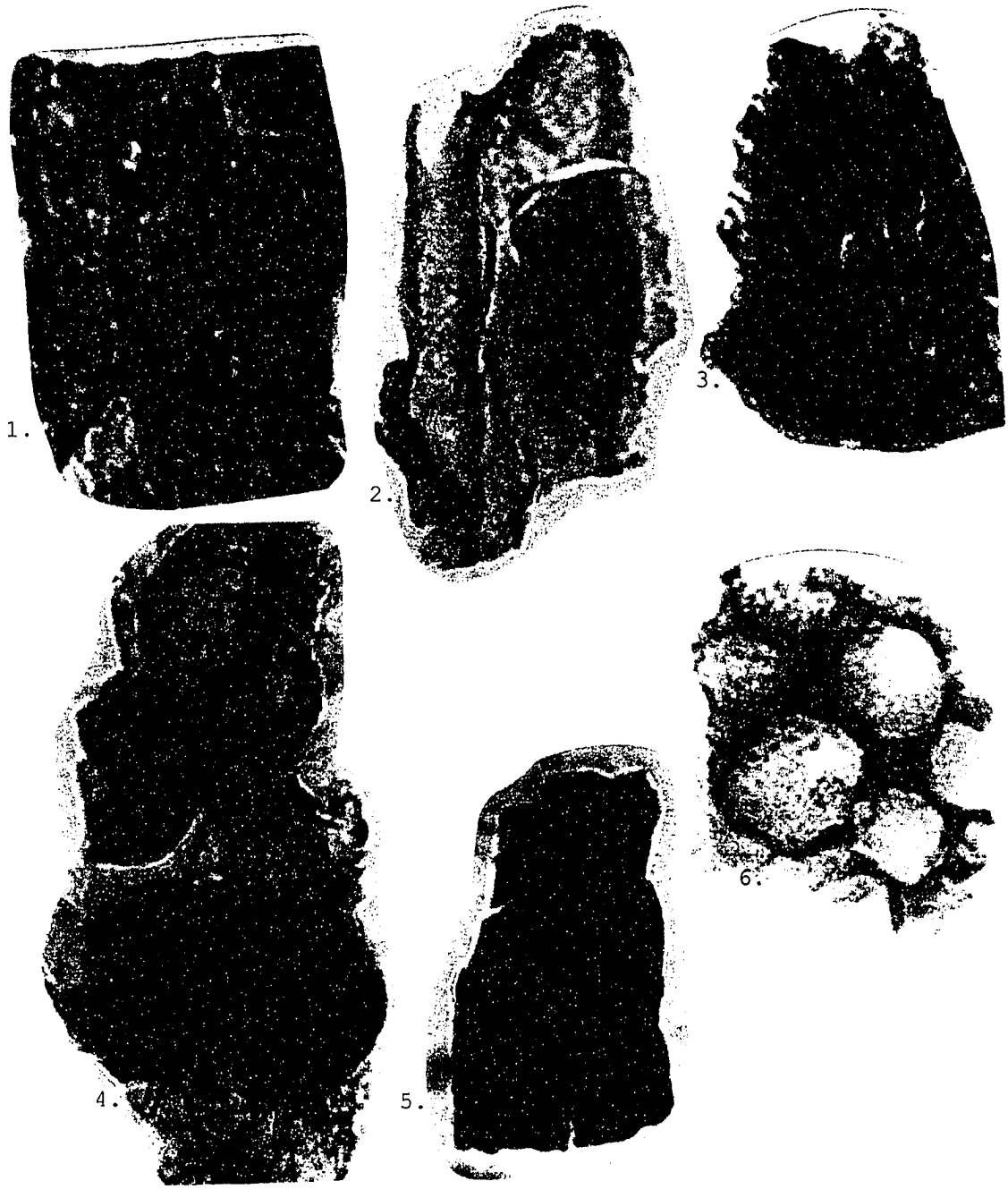
3. Wood: R22-35, ↑, 19U

4. cf. *Araucarioxylon* Tidwell 1998: R22-34, ↓, 25L

5. Wood: R22-33, ↓, 31G

6. Wood : R21-2, ↓, 16H

Plate 44



25 μm

Plate 45

Mazuma Creek Palynoflora
Florule B-5

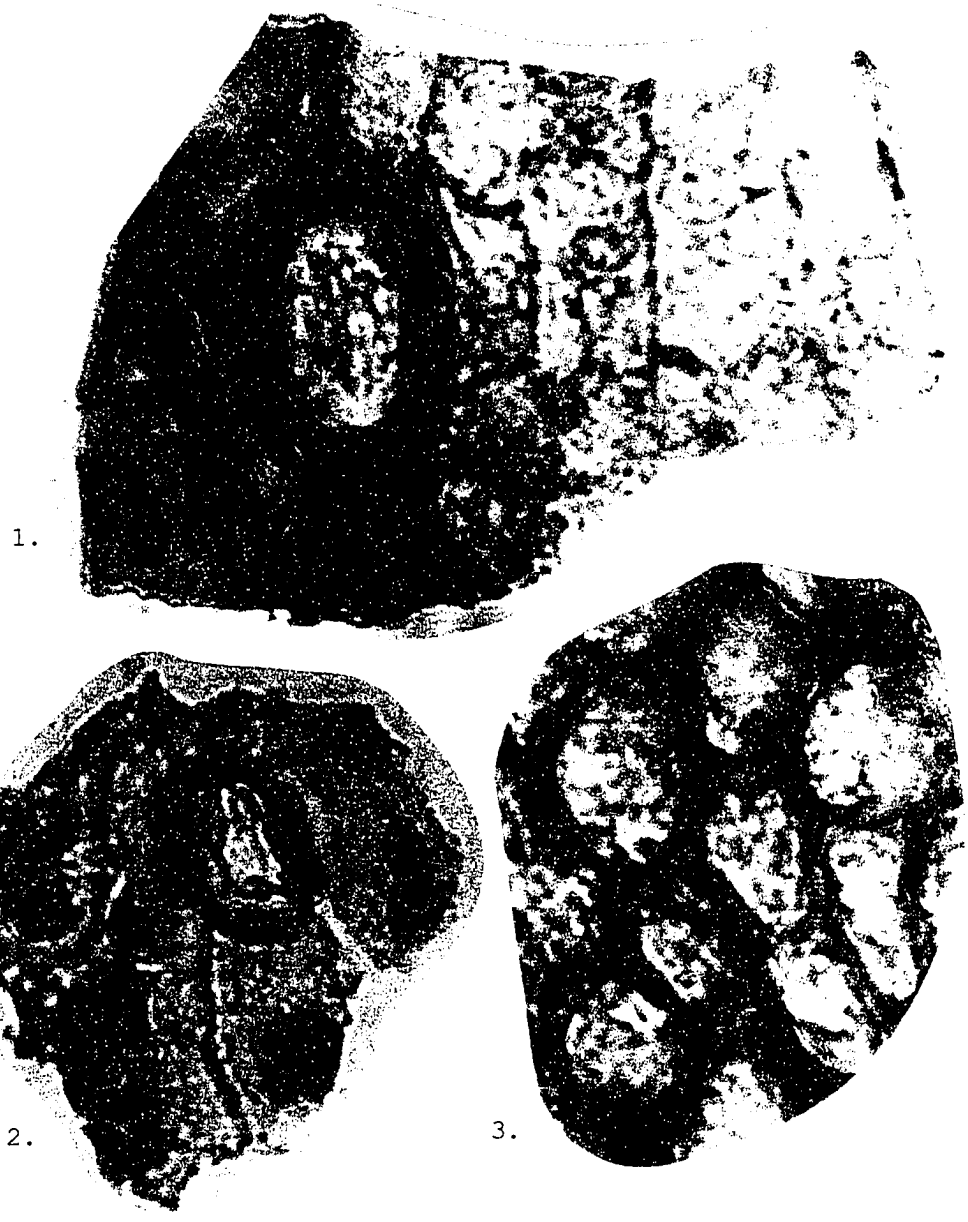
Slide No. 94SR (MZ) B005

1. Wood: R21-5, ↑, 6S

2. Wood: R21-10, ↑, 12R-S

3. Wood: R21-9, ↑, 11P

Plate 45



25 µm

Plate 46

Mazuma Creek Palynoflora
Florule B-5

Slide No. 94SR (MZ) B005

1. Wood: R21-1, ↓, 17F

2. Wood: R21-6, ↑, 7N-P

3. Wood: R21-4, ↑, 3R-S

Plate 46

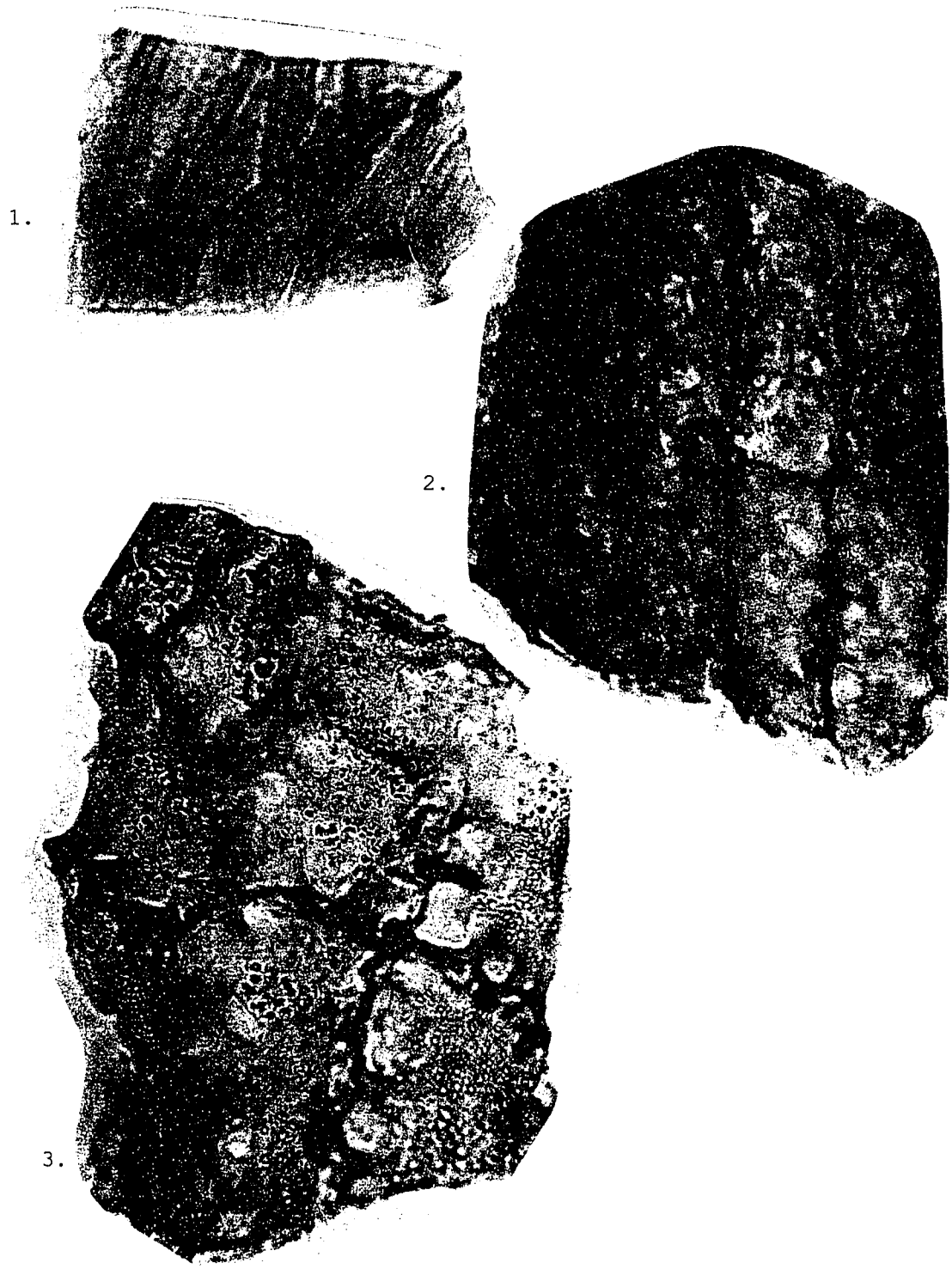


Plate 47

Mazuma Creek Palynoflora
Florule B-5

Slide No. 94SR (MZ) B005

1. *Retitriletes subreticulaesporites* (Rouse) Krutzsch 1963 : R21-32, ↑, 1-2J

2. *R. crassimacerius* (Hedlund) Burden and Hills 1989: R21-28, ↓, 18H

3. *Echinatisporis* sp.: R21-33, ↑, 2R

4. *Polypodiidites* sp.: R21-18, ↓, 37K-L

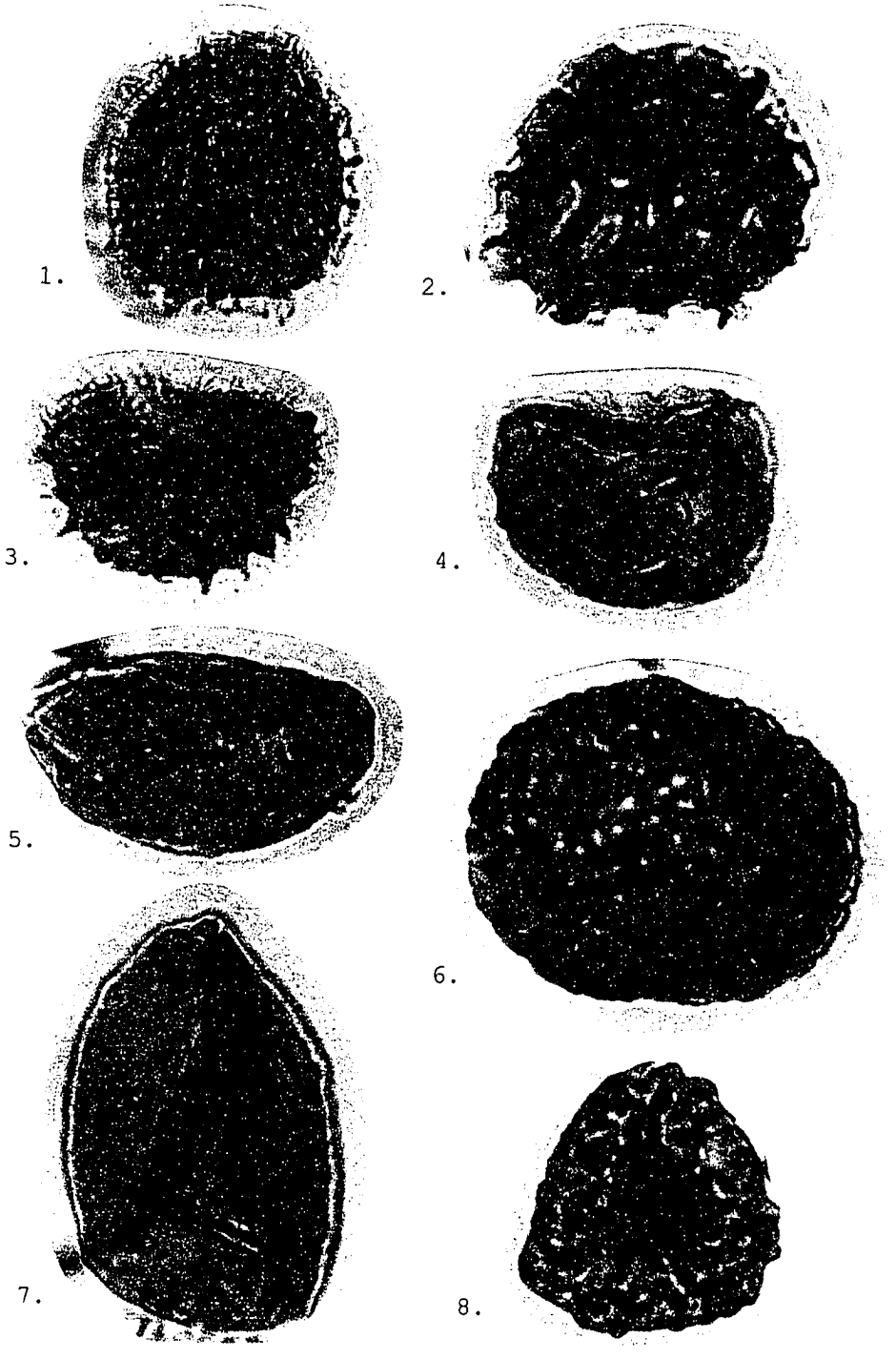
5. *Hazaria canadiana* Srivastava 1971: R21-29, ↓, 16-17P

6. *Camarozonosporites insignis* Norris 1967: R21-21, ↓, 31H

7. *Gleicheniidites* sp.: R21-25, ↓, 26F

8. *Camarozonosporites australiensis* Norvick and Burger 1975: R20-3, ↑, 12F

Plate 47



25 μm

Plate 48

Mazuma Creek Palynoflora
Florule B-5

Slide No. 94SR (MZ) B005

1. *Foraminisporis simiscalaris* (Paden, Phillips and Felix) Braman 2001: R21-34, ↑, 6-7H

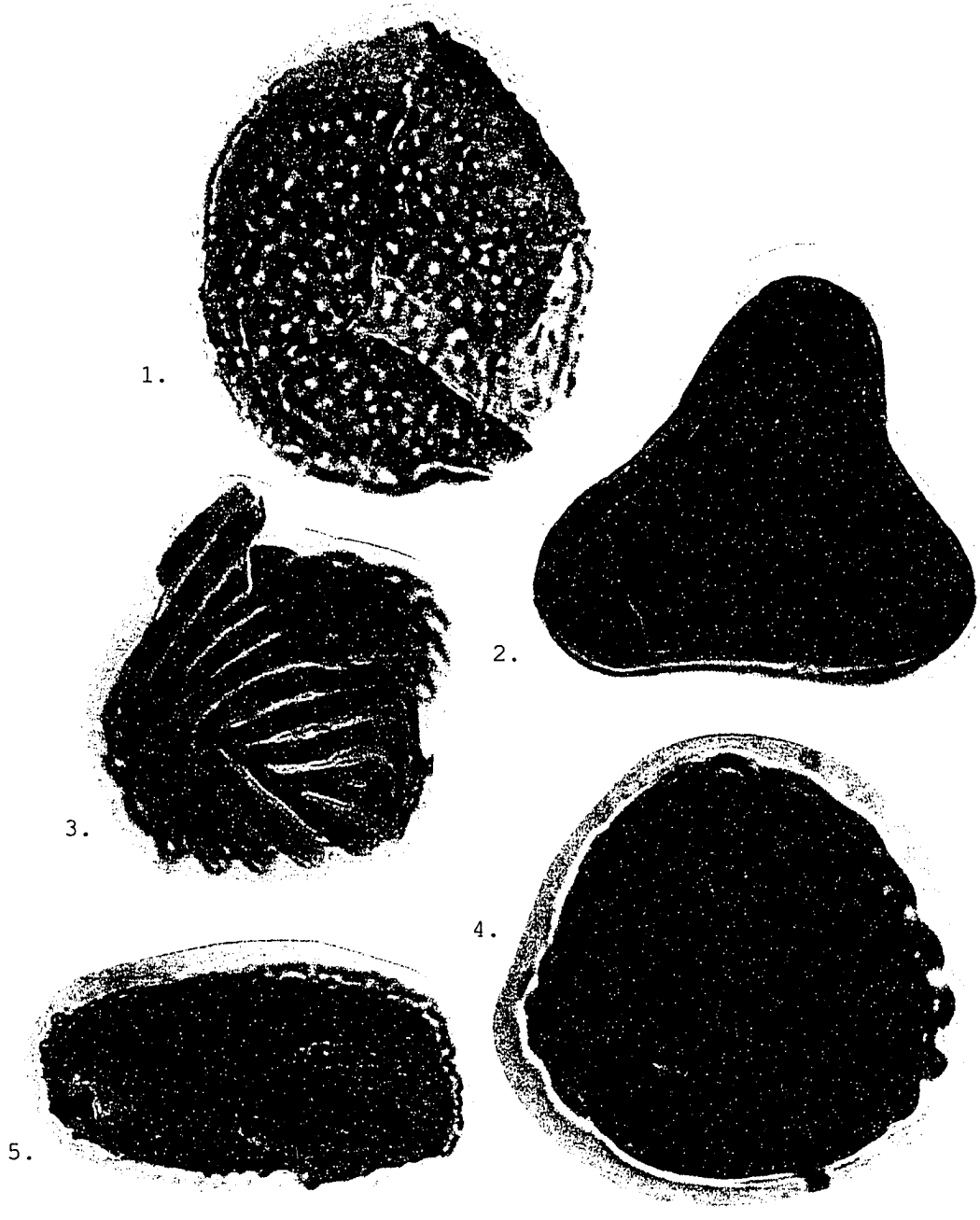
2. *Matonisporites crassiangulatus* (Balme) Dettmann 1963: R21-36, ↑, 9W

3. *Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann 1963: R21-20, ↓, 23K

4. *Cicatricosisporites* sp.: R21-17, ↓, 37D

5. *Cycadopites* sp.: R20-4, ↑, 13R

Plate 48



25 µm

Plate 49

Mazuma Creek Palynoflora
Florule B-5

Slide No. 94SR (MZ) B005

1. *Podocarpidites granulatus* Singh 1971: R21-27, ↓, 20V

2. *Parvisaccites* sp. cf. *P. radiatus* Couper 1958: R21-22, ↓, 26R

3. *Podocarpidites* sp.: R21-17, ↓, 37D

4. *Podocarpidites* sp.: R21-16, ↓, 37-38L

5. *Extraporopollenites* sp.: R21-35, ↑,8P

6. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: R21-24, ↓, 26-27F

Plate 49

APPENDIX C
Photographic Plates

Plate 50

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

1. *Laevigatosporites ovatus* Wilson and Webster 1946: R23-10, ↓, 27G

2. *Polypodiisporites* sp.: R22-22, ↑, 13P-14Q

3. *Polypodiisporites* sp.: R23-1, ↓, 36D

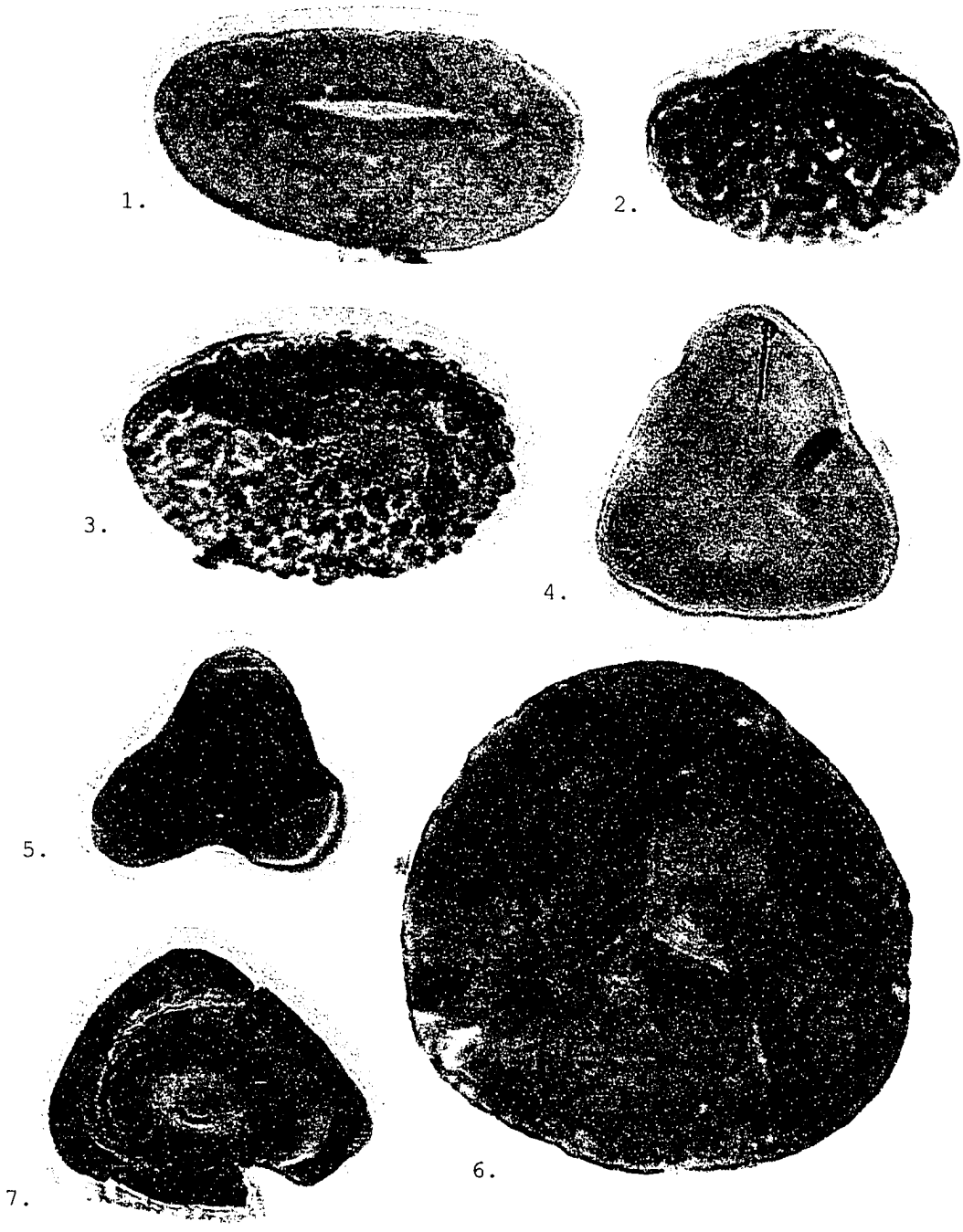
4. *Biretisporites potoniaei* Delcourt and Sprumont 1955: R22-18, ↑, 13G

5. *Cibotiumspora jurienensis* (Balme) Filatoff 1975: R23-3, ↓, 34F

6. *Todisporites* sp.: R23-22, ↑, 1P

7. *Stereiosporites antiquasporites* (Wilson and Webster) Dettmann 1963: R23-7, ↓, 30K

Plate 50



25 µm

Plate 51

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

1. *Reticulatisporites dupliexinous* Brenner 1963: R23-23, ↑, 1K

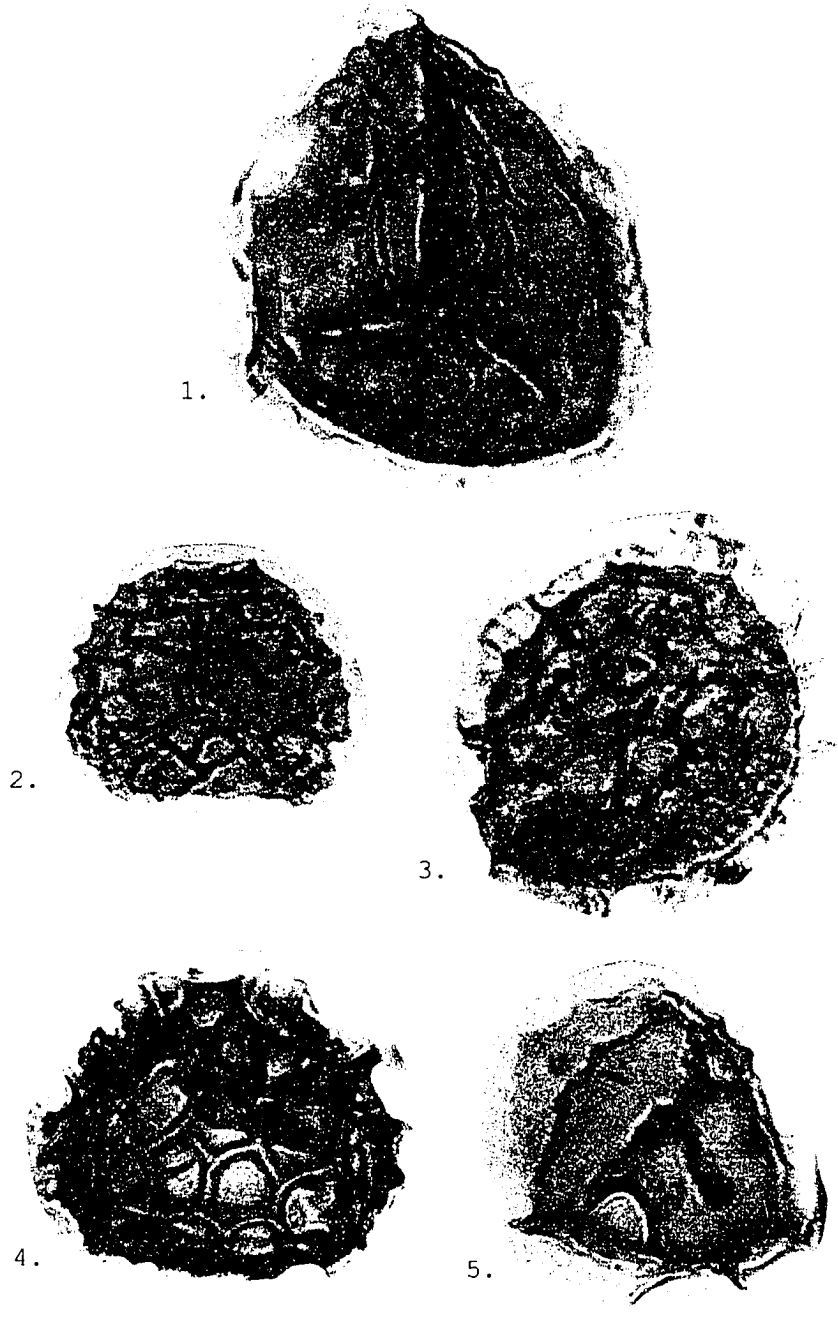
2. *Retitriletes* sp.: R22-26, ↑, 15N

3. *Retitriletes singhii* Srivastava 1972: R22-7, ↑, 11F

4. *Retitriletes clavatoides* (Cookson) Doring *et al.* 1963: R22-2, ↑, 9L

5. *Lycopodiumsporites marginatus* Singh 1964: R23-36, ↑, 9T

Plate 51



25 µm

Plate 52

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

1. *Hymenoreticulisporites castallatus* (Pocock) Doring 1964: R24-36, ↑, 5U

2. *Ceratosporites* sp. cf. *C. couliensis* Srivastava 1972: R23-20, ↓, 17Q

3. *Pilosisporites* sp.: R23-35, ↑, 8J

4. *Echinatisporis solaris* Braman 2001: R23-34, ↑, 7M

Plate 52

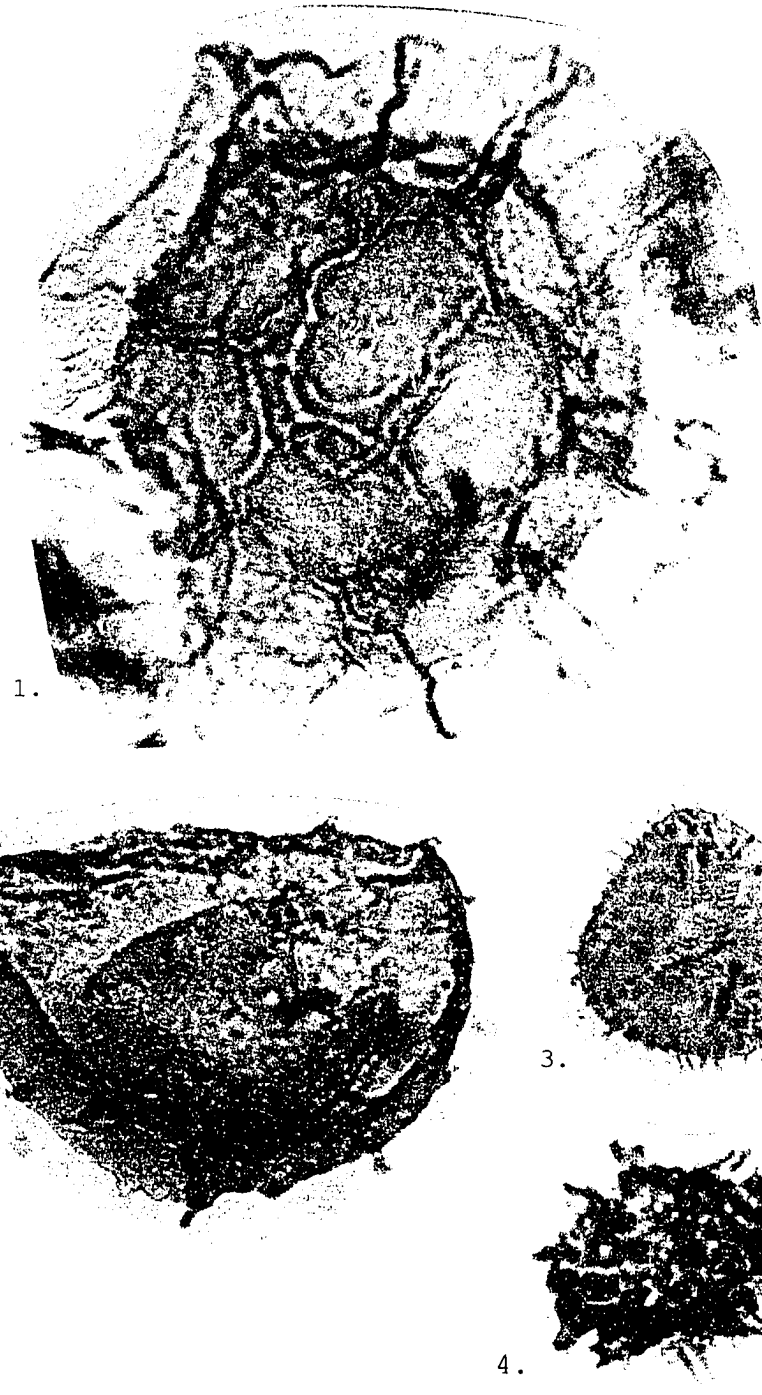


Plate 53

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

1. *Gleicheniidites delicatus* (Bolkhovitina) Pocock 1970: R22-12, ↑, 13S

2. *Foveosporites* sp.: 23-26, ↑, 3Q

3. *Foveosporites* sp.: R22-19, ↑, 13J

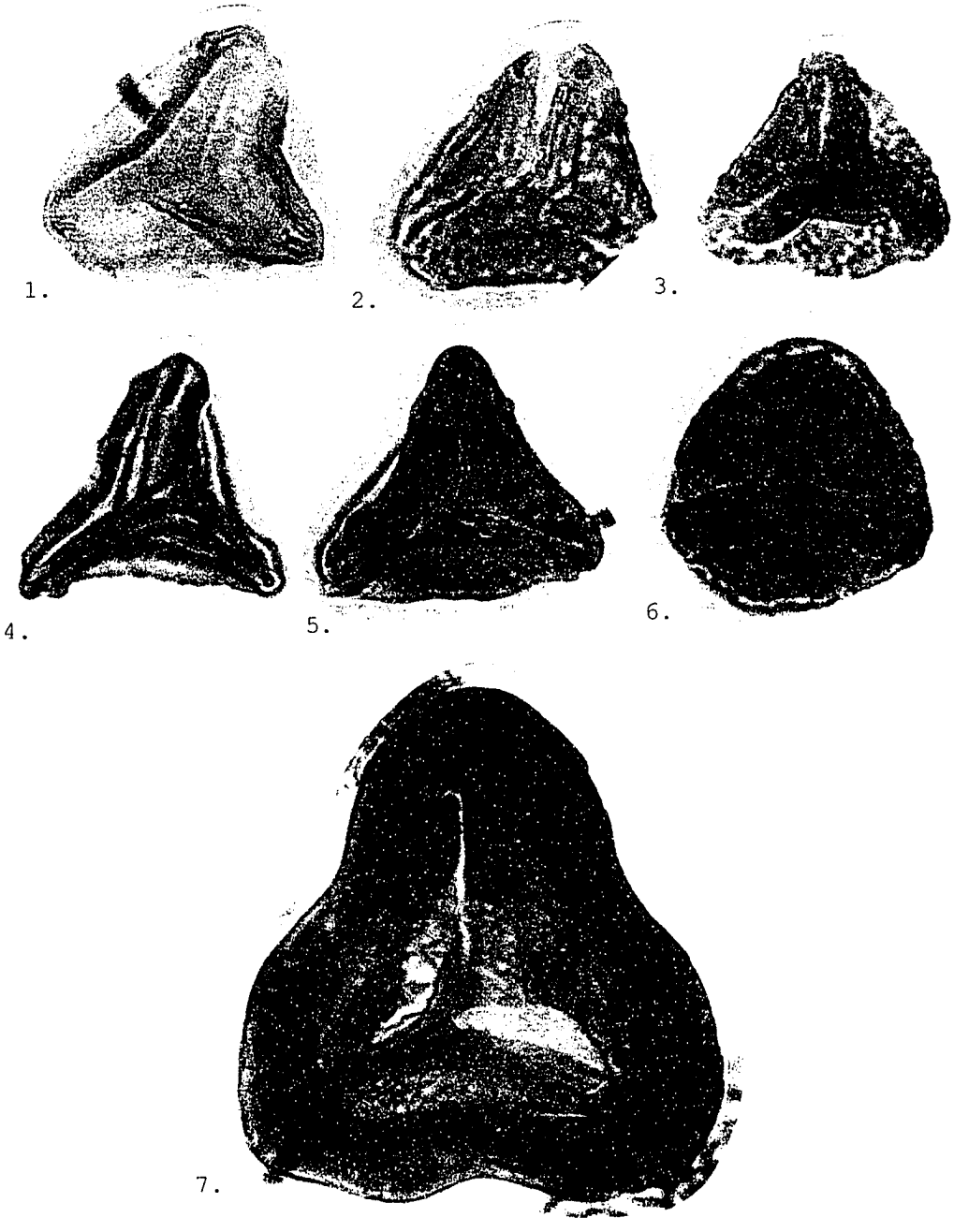
4. *Gleicheniidites* sp.: R23-29, ↑, 4W

5. *Dictyophyllidites mortonii* (de Jersey) Playford and Dettman 1965: R23-2, ↓, 36P

6. *Lygodioisporites verrucosus* Srivastava 1967: R23-33, ↑, 7P

7. *Distaltriangulatisporites perplexus* (Singh) Singh 1971: R24-32, ↓, 5G

Plate 53



25 µm

Plate 54

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

1. *Foveogleicheniidites confossus* (Hedlund) Burger in Norvick and Burger 1976: R22-20, ↑, 13L

2. *Conbaculatisporites* sp.: R23-32, ↑, 7P

3. *Verrucosisporites* sp.: R23-24, ↑, 1-2C

4. *Krauselisporites reissingerii* (Harris) Morby 1975: R23-15, ↓, 19D

5. *Baculatisporites* sp.: R23-9, ↓, 28E

6. *Baculatisporites conmaumensis* (Cookson) Potonié 1956: R23-30, ↑, 6F

Plate 54

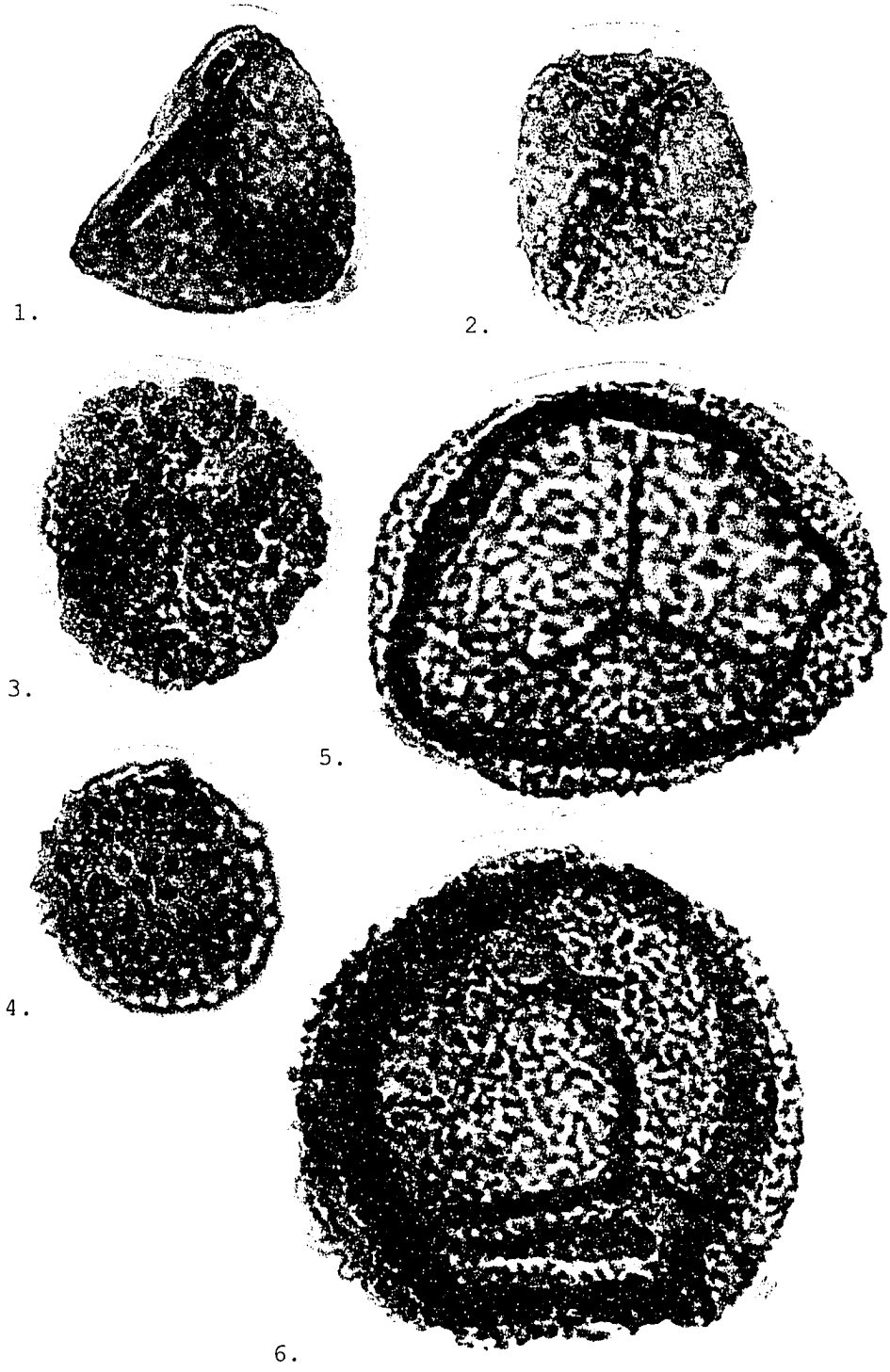


Plate 55

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

1. *Verrucosisporites major* (Couper) Burden and Hills 1989: R23-16, ↓, 18Q

2. *Camarozonosporites insignis* Norris 1967: R22-28, ↑, 14K

3. *Cicatricosisporites* sp: R23-17, ↓, 18U

4. *Cicatricosisporites radiatus* Krutzsch 1959: 23-12, ↑, 13S

5. *Cicatricosisporites* sp.: R22-13, ↑, 13N

6. *Cicatricosisporites* sp.: R22-8, ↑, 11P

Plate 55

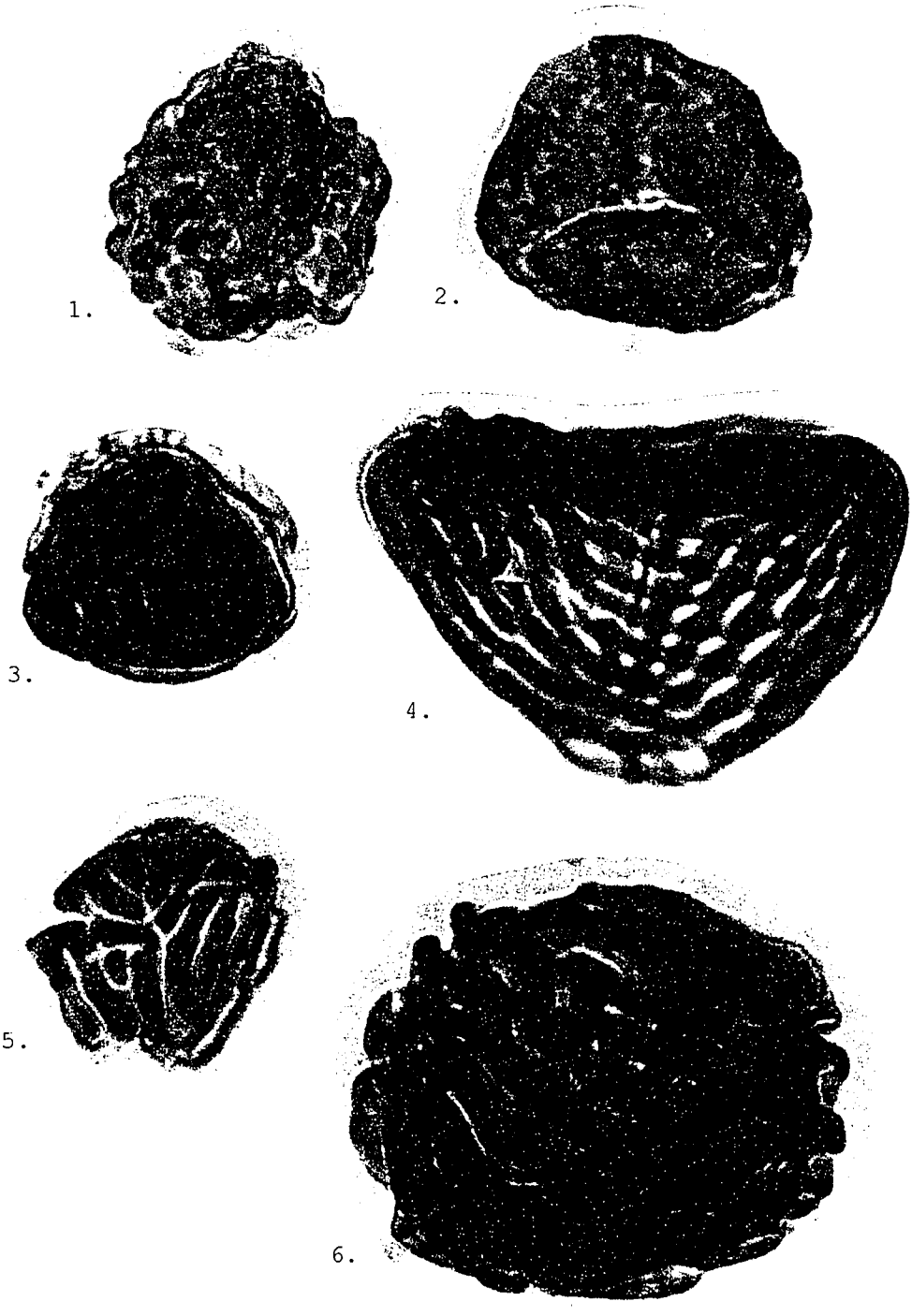


Plate 56

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

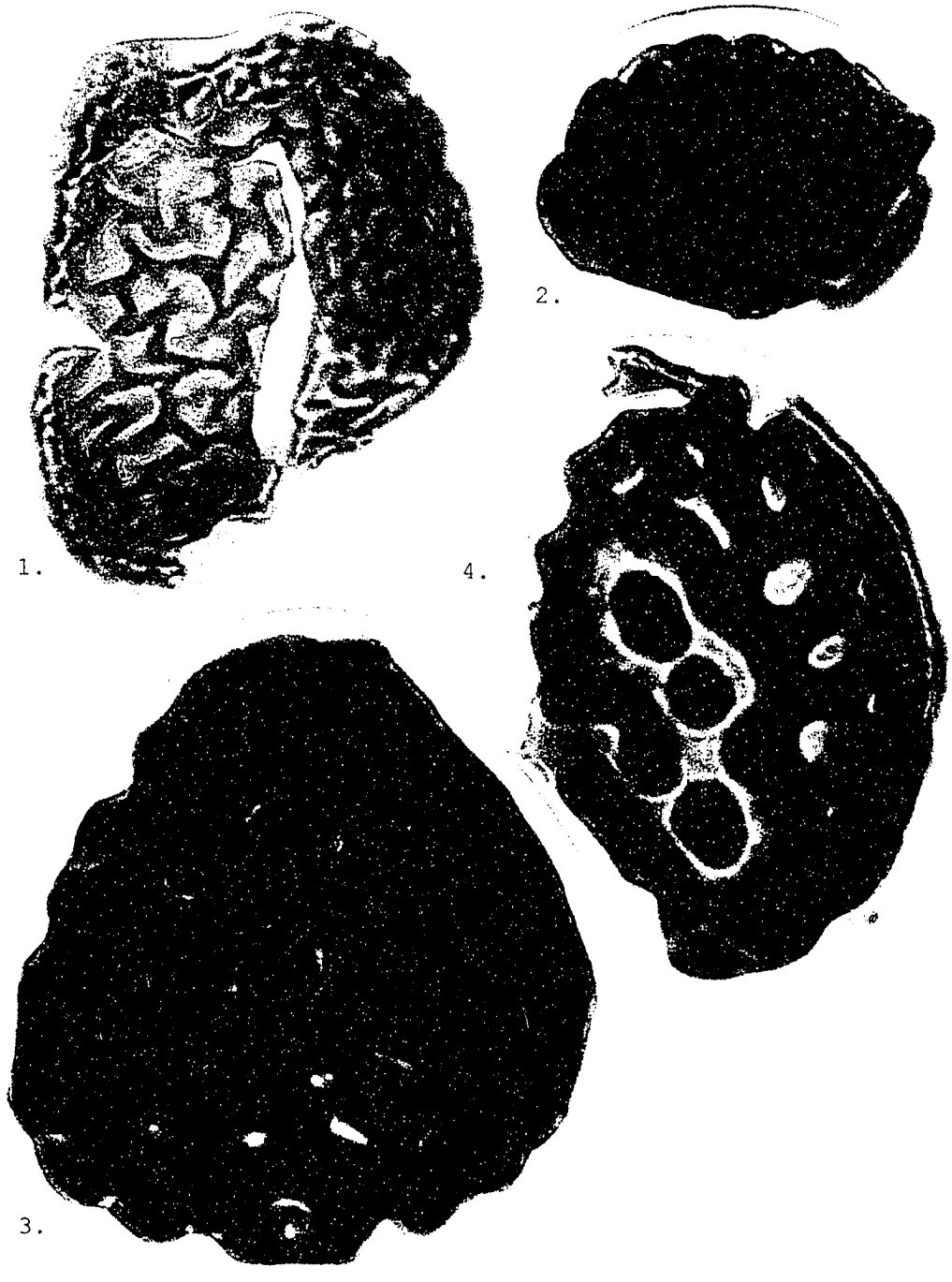
1. *Lycopodiacidites canaliculatus* Singh 1971: R22-14, ↑, 13K

2. *Lycopodiacidites caperatus* Singh 1971: R22-4, ↑, 9X

3. *Klukisporites pseudoreticulatus* Couper 1958: R22-16, ↑, 13H

4. *K. pseudoreticulatus*: R22-9, ↑, 11H

Plate 56



25 µm

Plate 57

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

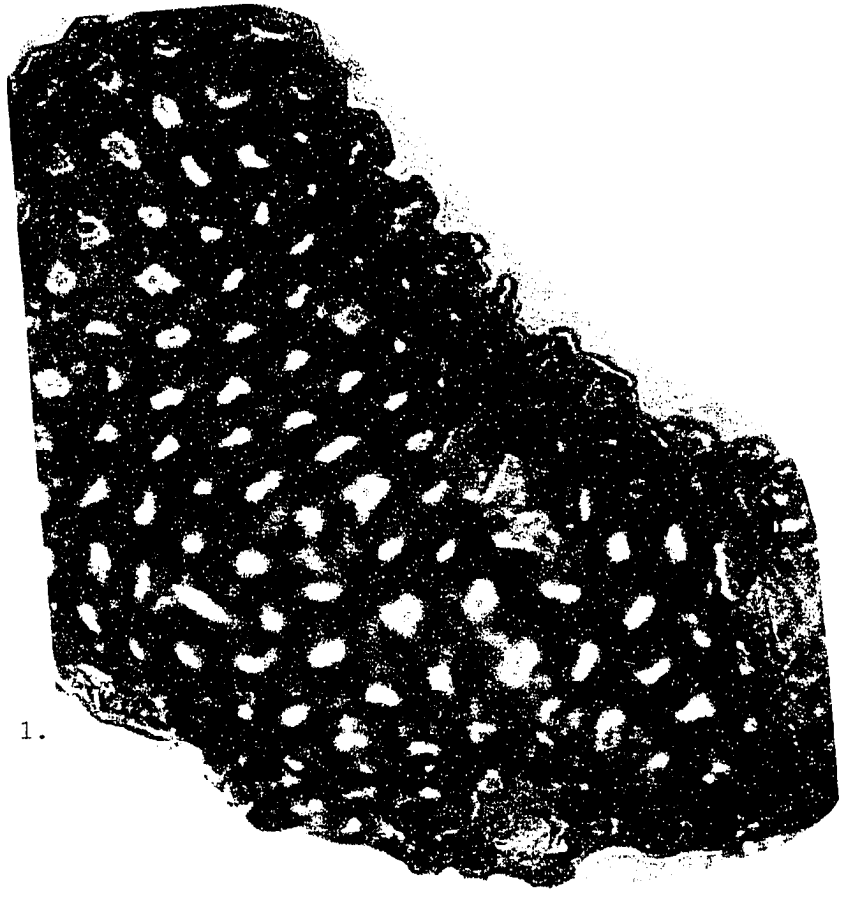
1. *Schizaea reticulata* Cookson 1956: R22-21, ↑, 13S

2. *Cycadopites reticulatus* (Nilsson) Cornet and Traverse 1975: R22-3, ↑, 9R-10S

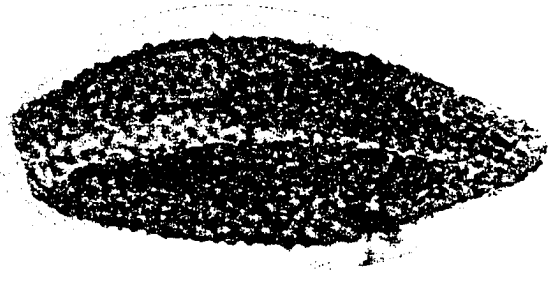
3. *Taxodiaceaepollenites hiatus* (Potonié) Kremp 1949: R22-15, ↑, 13J

Plate 57

1.



2.



3.

25 µm

Plate 58

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

1. *Abiespollenites* sp.: R22-27, ↑, 15L

2. *Podocarpidites granulatus* Singh 1971: R24-35, ↑, 3-4E

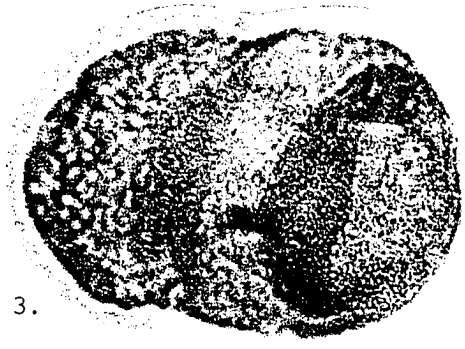
3. *Piceapollenites* sp.: R22-29, ↑, 15U

4. *Podocarpidites canadensis* (Pocock) Singh 1971: R23-28, ↑, 4N

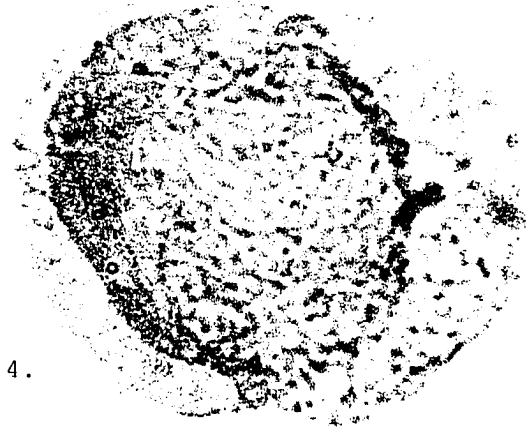
Plate 58

1.

2.



3.



4.

25 µm

Plate 59

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

1. *Abietipites* sp.: R23-5, ↓, 32-33

2. *Podocarpidites canadensis* (Pocock) Singh 1971: R23-21, ↓, 16F

3. *Piceapollenites* sp.: R23-19, ↓, 17T

4. *Podocarpidites multesimus* (Bolkovitina) Pocock 1962: R23-18, ↓, 17U

Plate 59

Plate 60

Mazuma Creek Palynoflora
Florule C-1

Slide No. 94SR (MZ) C001

1. *Extraporopollenites* sp.: R23-13, ↓, 12U

2. *Trudopollis pertrudens* (Pflug *in* Thompson and Pflug 1953a) Pflug 1953: R23-4, ↓, 33Q

3. *Proteacidites retusus* Anderson 1960: R22-5, ↑, 10Q

4. *Retitricolpites georgensis* Brenner 1963: R23-14, ↓, 9D

5. *R. georgensis*: R22-6, ↑, 10M-N

6. cf. *Anacolosidites* sp.: R23-26, ↑, 3Q

7. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: R23-11, ↓, 24Q

8. cf. *Anacolosidites* sp.: R23-27, ↑, 4U

9. *Aquilapollenites spinulosus* Funkhouser 1961: R24-33/34, ↓, 21F

10. *Aquilapollenites augustus* Srivastava 1969: R23-8, ↓, 29L

Plate 60

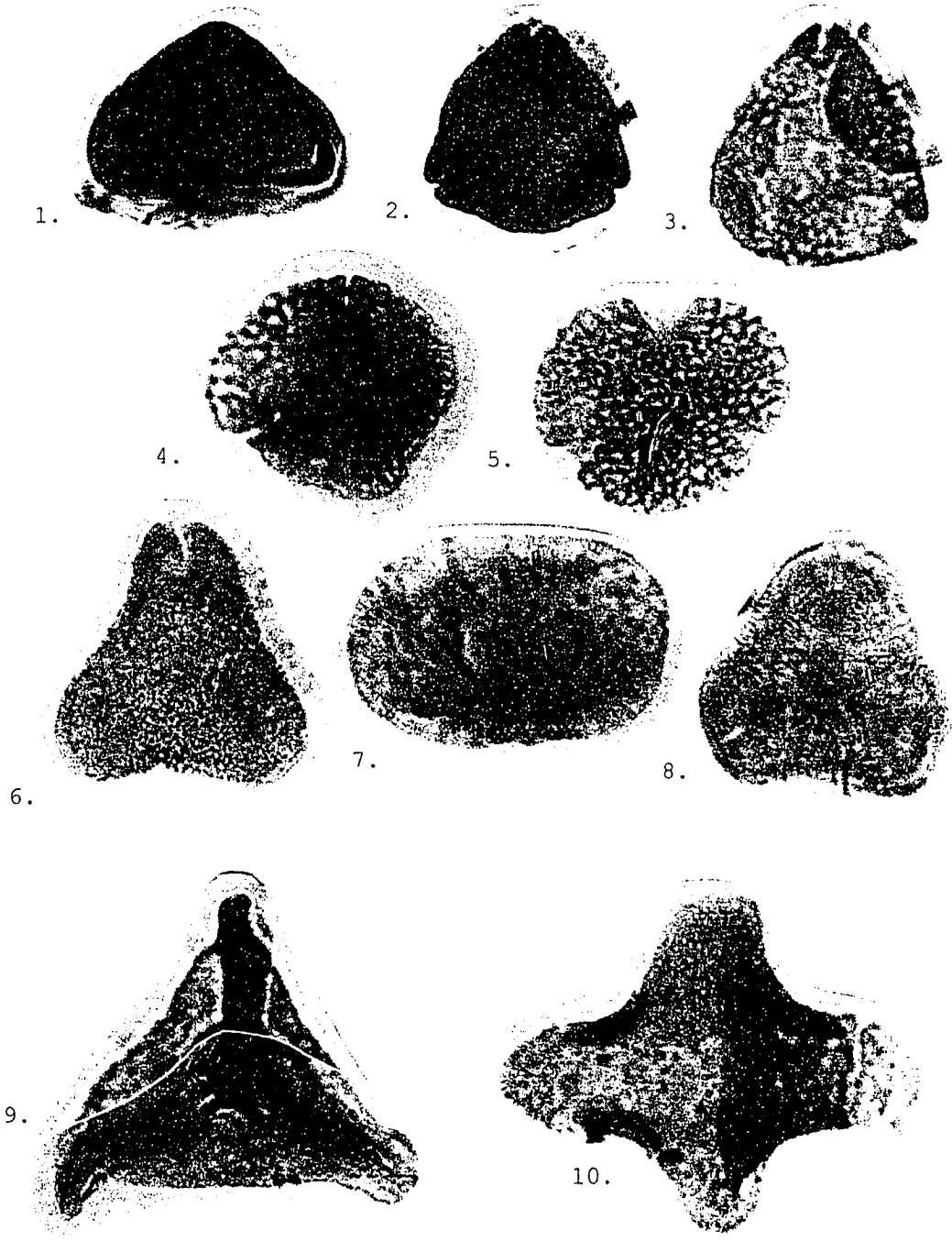


Plate 61

Mazuma Creek Palynoflora
Florule C-2

Slide No. 94SR (MZ) C002

1. *Laevigatosporites gracile* Wilson and Webster 1946: R24-10, ↓, 26H

2. *Cyathidites minor* Couper 1953: R24-26, ↑, 11M

3. *Concavissimisporites* sp. B: R24-25, ↑, 7-8N

4. *Undulatisporites fossulatus* Singh 1971: R24-23, ↑, 3V

5. *Stereisporites antiquasporites* (Wilson and Webster) Dettmann 1963: R24-22, ↑, 3T

6. *Deltoidospora hallii* Miner 1935: R24-24, ↑, 6M

7. *Retitriletes subreticulaesporites* (Rouse) Krutzsch 1963: R24-18, ↓, 17X-Y

8. *Retitriletes clavatoides* (Couper) Doring *et al.* 1963: R24-16, ↓, 20W

9. *Gemmatriletes morulus* Pierce 1961: R24-4, ↓, 7U

10. *Foveogleicheniidites confossus* (Hedlund) Burger *in* Norvick and Burger 1976: R24-21, ↑, 1-2F

Plate 61

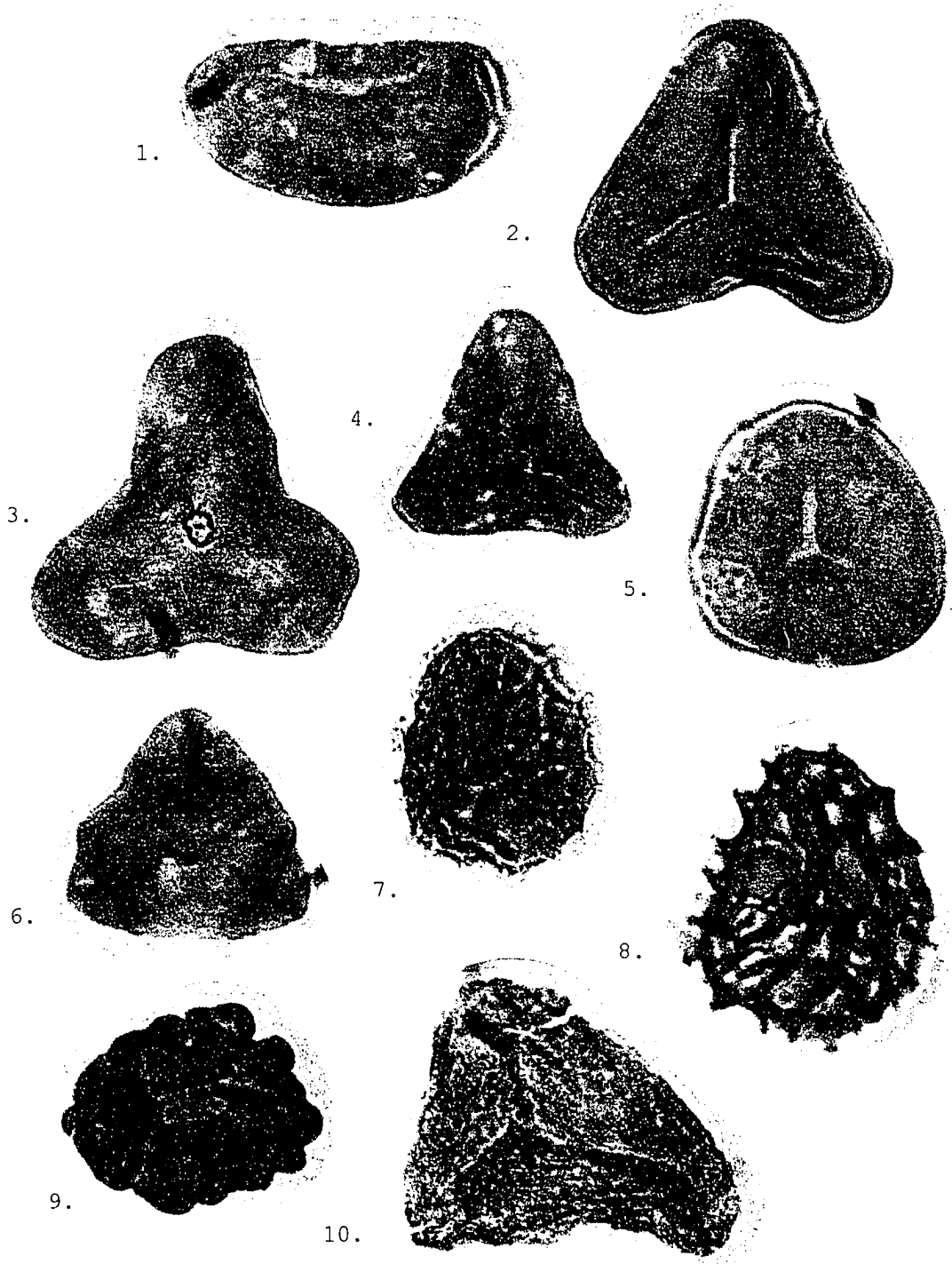


Plate 62

Mazuma Creek Palynoflora
Florule C-2

Slide No. 94SR (MZ) C002

1. *Distaltriangulisporites perplexus* (Singh) Singh 1971: R24-30, ↑, 13T

2. *Cicatricosisporites imbricatus* (Markova) Singh 1971: R24-28, ↑, 13-14L

3. *Cicatricosisporites* sp.: R24-12, ↓, 23R

4. *Cicatricosisporites* sp.: R24-9, ↓, 27M

5. *Cicatricosisporites hallei* Delcourt and Sprumont 1955: R24-8, ↓, 33X

Plate 62

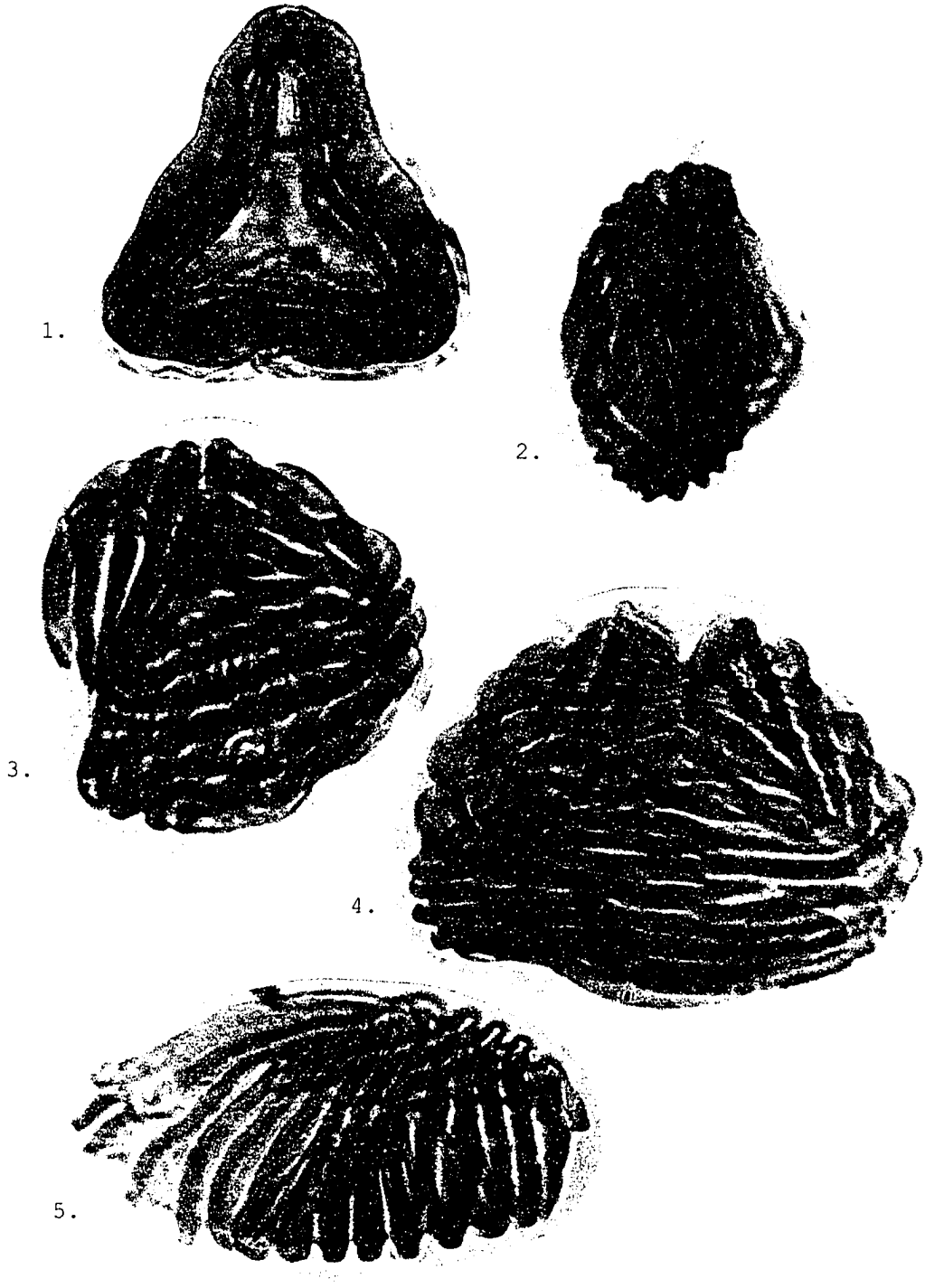


Plate 63

Mazuma Creek Palynoflora
Florule C-2

Slide No. 94SR (MZ) C002

1. *Neoraistrickia* sp.: R24-14, ↓, 32W

2. *Taurocuspidites segmentatus* Stover 1962: R24-20, ↑, 1P

3. *Schizaea reticulata* Cookson 1956: R24-15, ↓, 22D

Plate 63

25 µm

Plate 64

Mazuma Creek Palynoflora
Florule C-2

Slide No. 94SR (MZ) C002

1. *Podocarpidites canadensis* Singh 1971: R24-31, ↑, 15F

2. *Abiespollenites* sp.: R24-11, ↓, 25S

3. *Ulmoideipites herbridicus* (Simpson) Sweet 1986: R24-19, ↓, 16R

Plate 64

1.

2.

3.

25 µm

Plate 65

Mazuma Creek Palynoflora
Florule C-2

Slide No. 94SR (MZ) C002

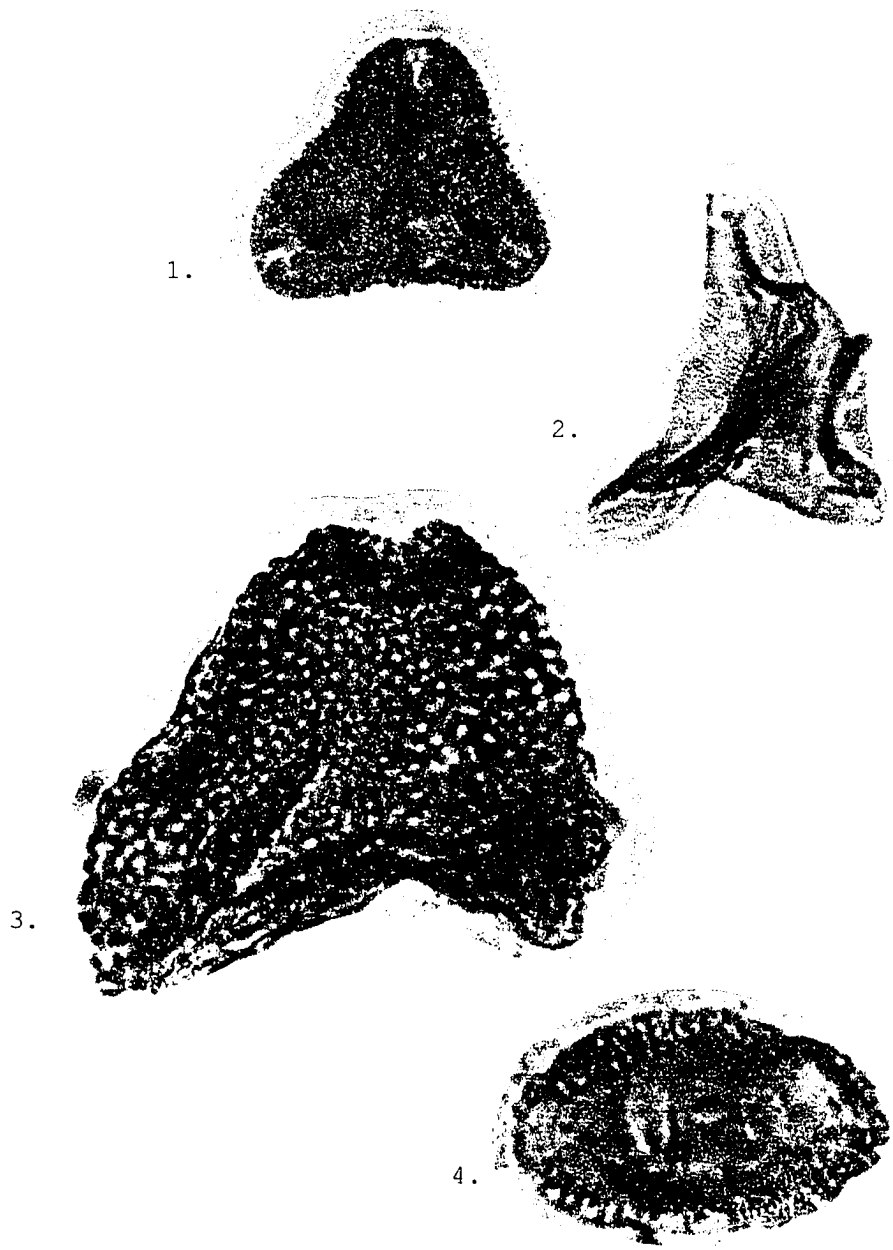
1. cf. *Anacolosidites* sp.: R24-13, ↓, 23S

2. *Scollardia trapaformis* Srivastava 1966: R24-29, ↑, 13T

3. *Proteacidites auratus* Srivastava 1969: R24-5, ↓, 23D

4. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: R24-7, ↓, 27N

Plate 65



25 µm

Plate 66

Mazuma Creek Palynoflora
Florule C-3

Slide No. 94SR (MZ) C003

1. *Cyathidites australis* Couper 1953: R25-24, ↑, 6F

2. *Cyathidites minor* Couper 1953: R25-32, ↑, 15M

3. *Gleicheniidites* sp.: R25-15, ↓, 16K

4. *Gleicheniidites senonicus* (Ross) Delcourt and Sprumont 1955: R25-18, ↑, 3S

5. *Gleicheniidtes umbonatus* (Bolkhovitina) Bolkhovitina 1968: R25-30, ↑, 14E

6. *Dictyophyllidites* sp.: R25-5, ↓, 34S

7. *Cingutriletes* sp.: R25-25, ↑, 7-8M

8. *Lycopodiumsporites crassimacerius* Hedlund 1966, proximal view: R25-13, ↓, 16T

Plate 66

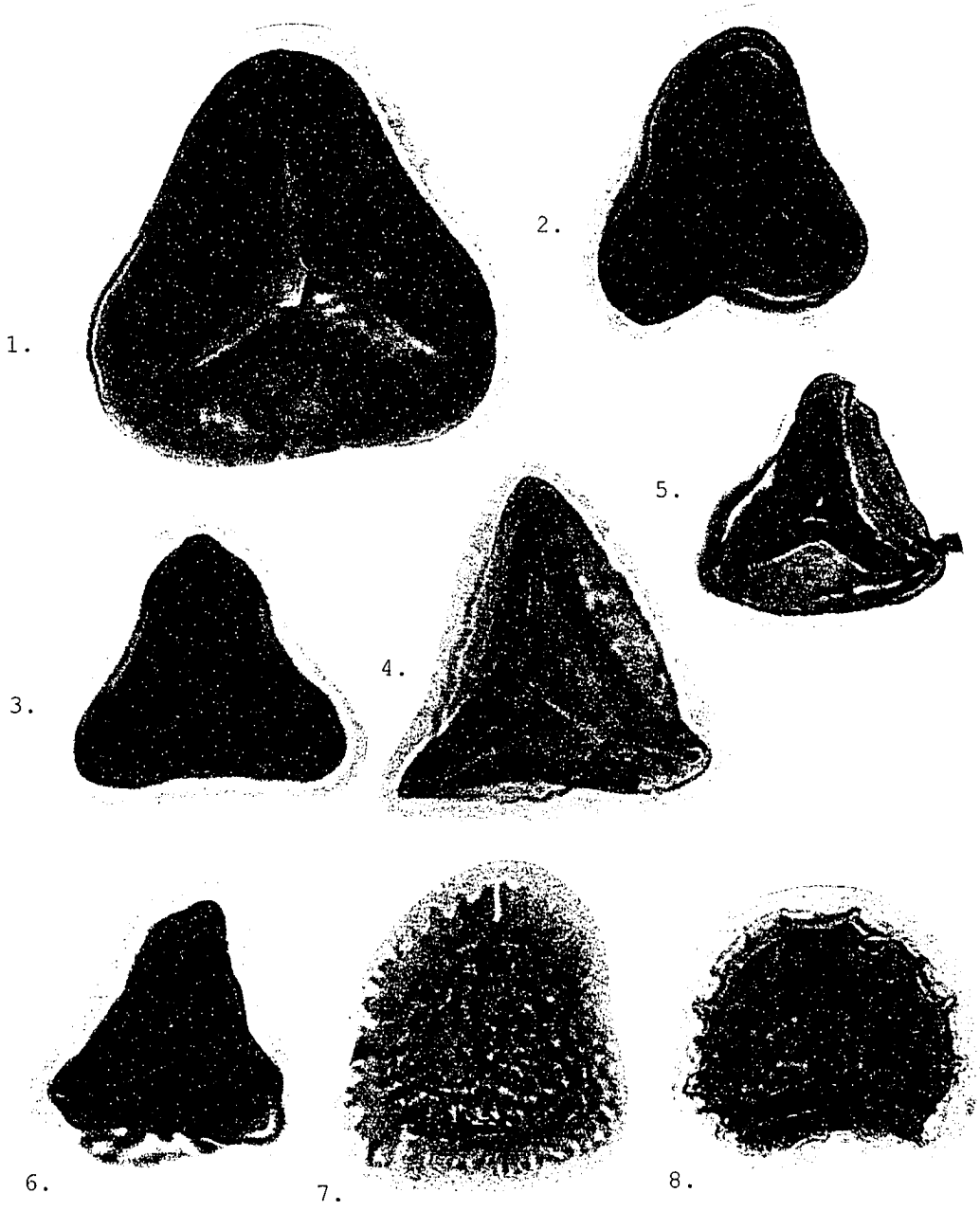


Plate 67

Mazuma Creek Palynoflora
Florule C-3

Slide No. 94SR (MZ) C003

1. *Lycopodiumsporities crassimacerius* Hedlund 1966, distal view: R25-33, ↑, 16M

2. *Lycopodiumsporites crassatus* Singh 1971: R 25-26, ↑, 9N

3. *Foveosporites* sp.: R25-14, ↑, 14P

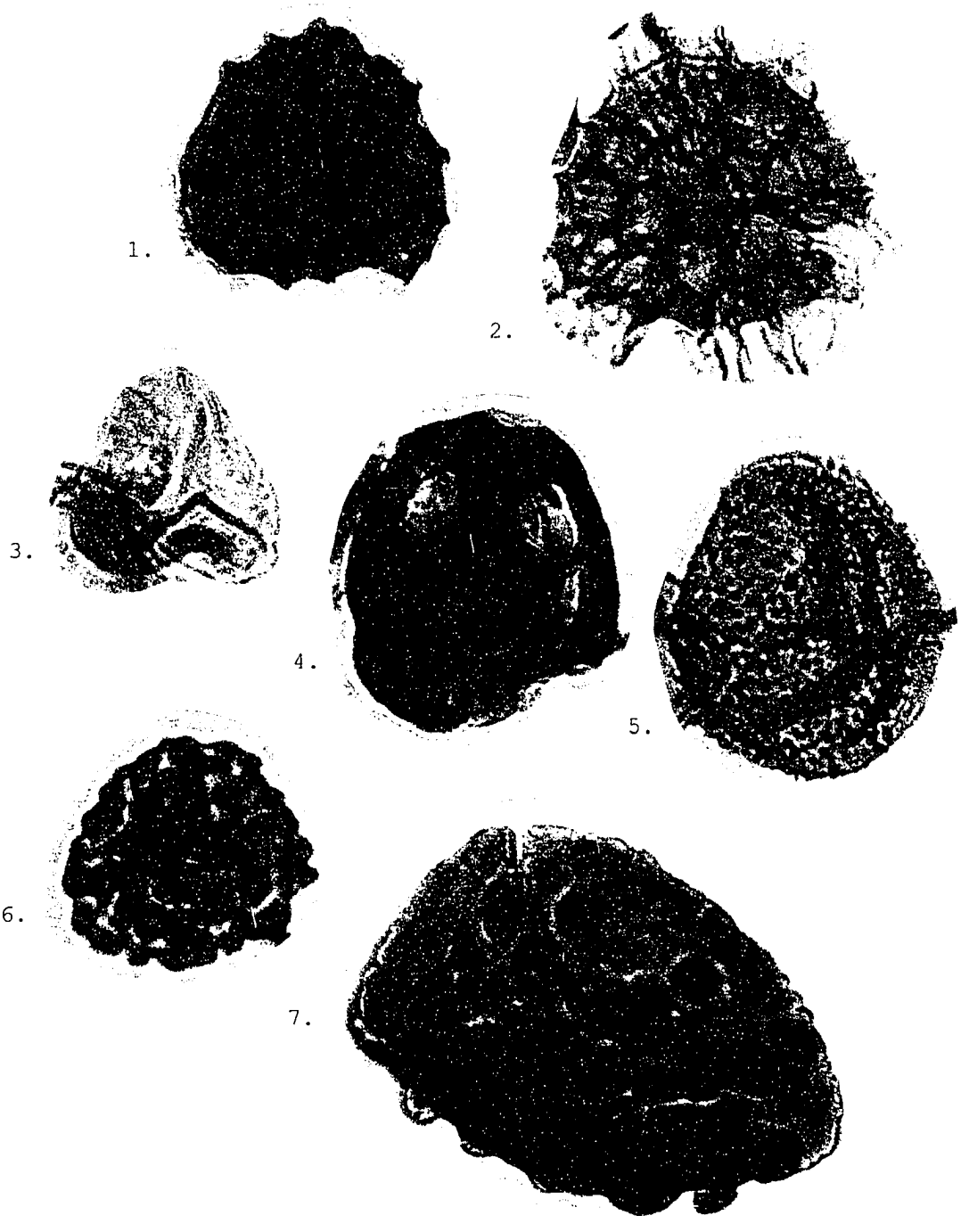
4. *Triporoletes radiatus* (Dettmann) Playford 1971: R25-14, ↓,17H

5. *Baculatisporites* sp.: R25-7, ↓, 31-L-M

6. *Verrucosisporites major* (Couper) Burden and Hills 1989: R25-10, ↓, 21H

7. *Taurocuspidites segmentatus* Stover 1962: R25-17, ↑, 2H

Plate 67



25 µm

Plate 68

Mazuma Creek Palynoflora
Florule C-3

Slide No. 94SR (MZ) C003

1. *Cicatricosisporites* sp.: R25-6, ↓,33-34D

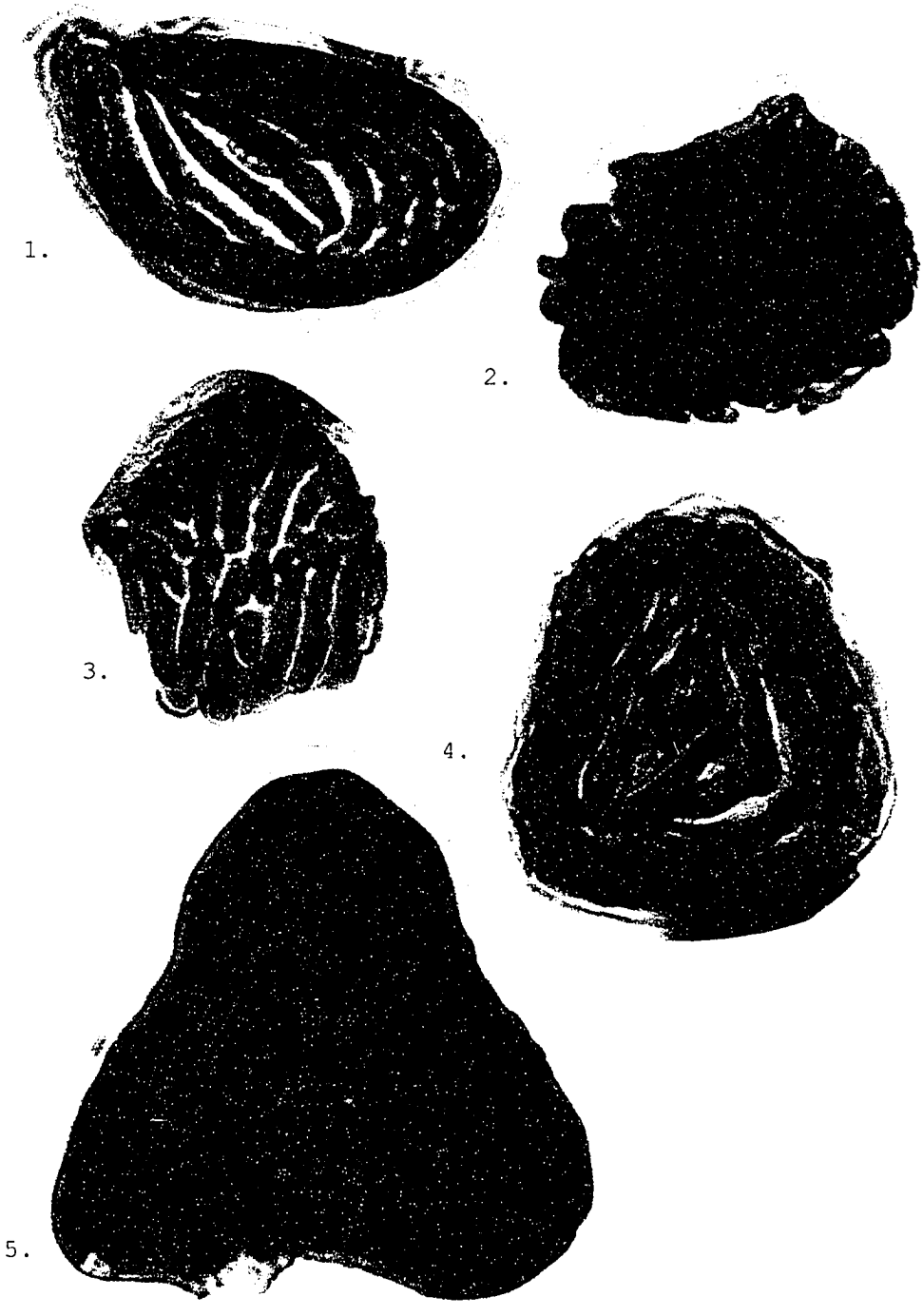
2. *Cicatricosisporites* sp.: R25-11, ↓, 12R

3. *Cicatricosisporites radiatus* Krutzsch 1959: R25-29, ↑,12R

4. *Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann 1963: R25-27, ↑, 9-10N

5. *Distaltriangulatisporites perplexus* (Singh) Singh 1971: R25-8, ↓, 26L

Plate 68



25 µm

Plate 69

Mazuma Creek Palynoflora
Florule C-3

Slide No. 94SR (MZ) C003

1. *Neoraistrickia* sp.: R25-36, ↑, 17U

2. *Microreticulatisporites crassiexinous* Brenner 1963: R25-16, ↑, 1T

3. *Foveasporis* sp. cf. *F. linearis* Krutzsch 1959: R25-35, ↑, 16X

Plate 69

25 μm

Plate 70

Mazuma Creek Palynoflora
Florule C-3

Slide No. 94SR (MZ) C003

1. *Lycopodiacidites canaliculatus* Singh 1971: R25-21, ↑, 5T

2. *Hamulatisporis amplus* Stanley 1965: R25-4, ↓, 36X

3. *Cycadopites reticulatus* (Nilsson) Cornet and Tranverse 1975.: R25-19, ↑, 3-4W

Plate 70

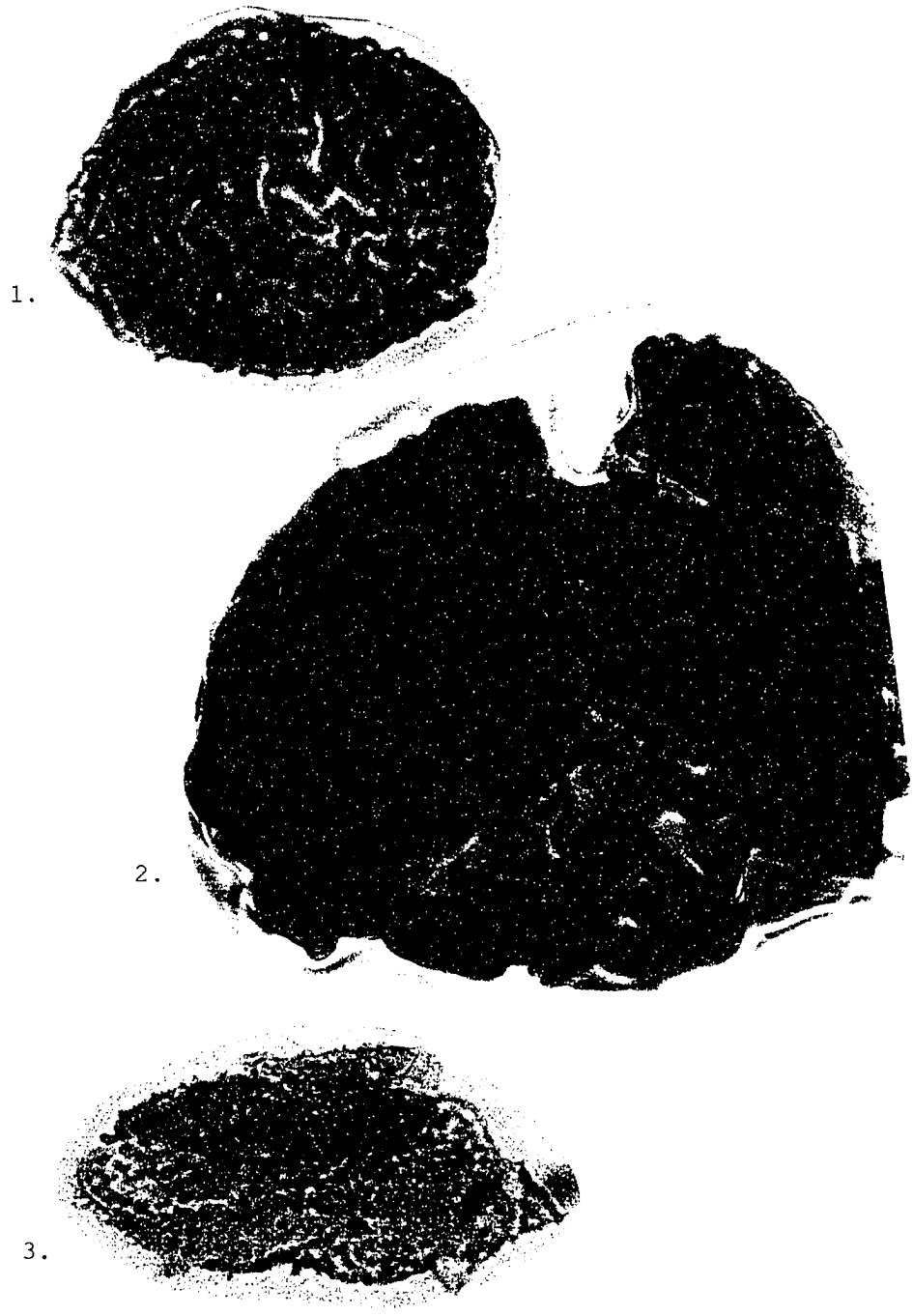


Plate 71

Mazuma Creek Palynoflora
Florule C-3

Slide No. 94SR (MZ) C003

1. *Alisporites grandis* (Cookson 1953b) Dettman 1963: R25-20, ↑, 4R

2. *Cedripites cretaceus* Pocock 1962: R25-34, ↑, 16H

3. *Parvisaccites radiatus* Couper 1958: R25-23, ↑, 6G

4. *Pityosporites elongatus* var. *grandis* Tschudy 1973: R25-22, ↑, 5K

Plate 71

Plate 72

Mazuma Creek Palynoflora
Florule C-3

Slide No. 94SR (MZ) C003

1. *Deltoidospora neddeni* (Potonié) Orbell 1973: R25-9, ↓, 25L

2. *Extraporopollenites* sp.: R25-1, ↓, 4J

3. *Rousea subtilis* Srivastava 1970: R25-2, ↓, 3J

4. *Erdtmanipollis albertensis* Srivastava 1969: R25-12, ↓, 18-19P

5. *E. albertensis*: R25-28, ↑, 11-12X

6. *Proteacidites retusus* Anderson 1960: R25-3, ↓, 7F

Plate 72

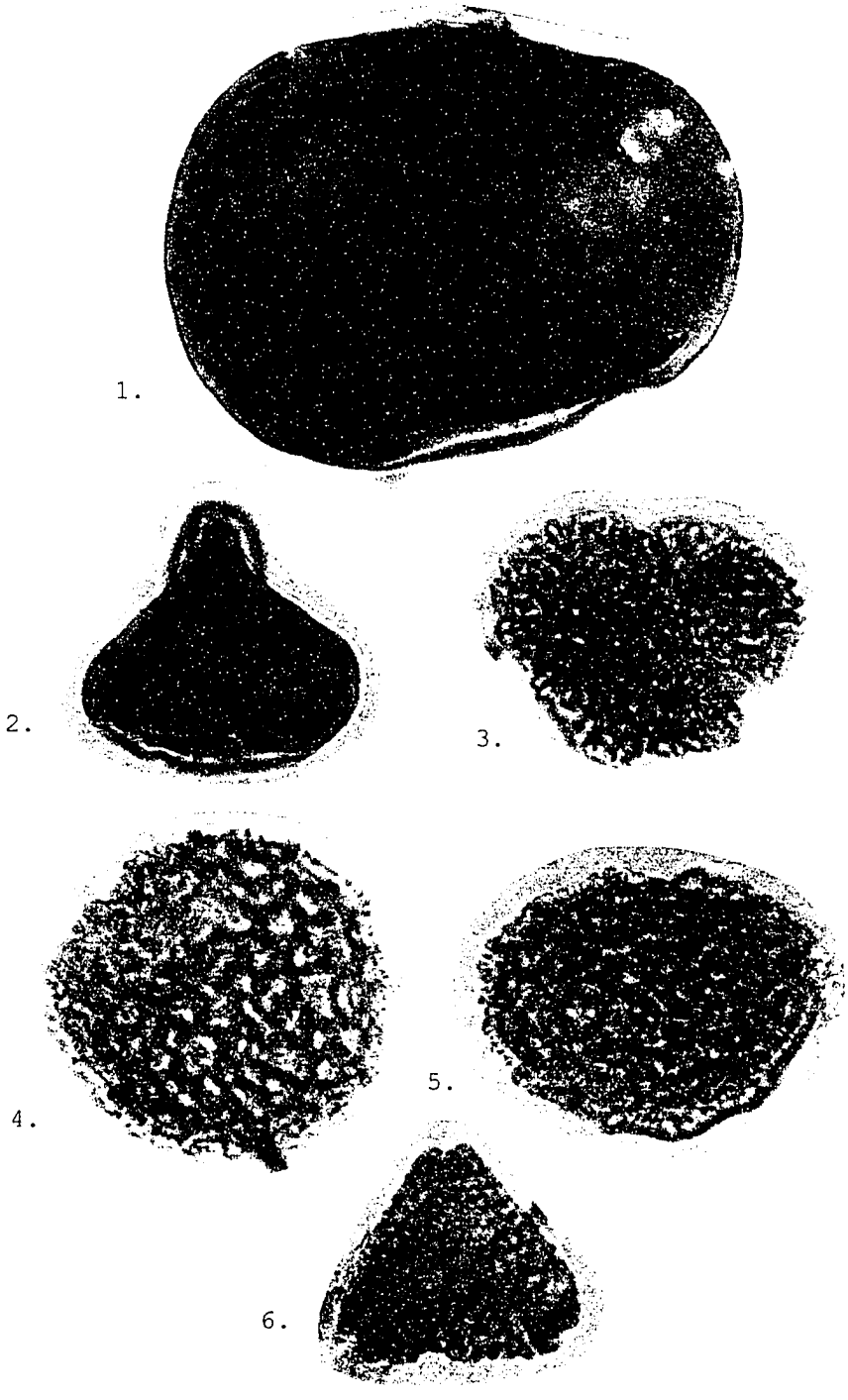


Plate 73

Mazuma Creek Palynoflora
Florule C-4

Slide No. 94SR (MZ) C004

1. *Microfoveolatosporis pseudoreticulatus* (Hedlund) Singh 1983: R13-23, ↑, 7C

2. *Polypodiidites* sp.: R13-28, ↑, 12J

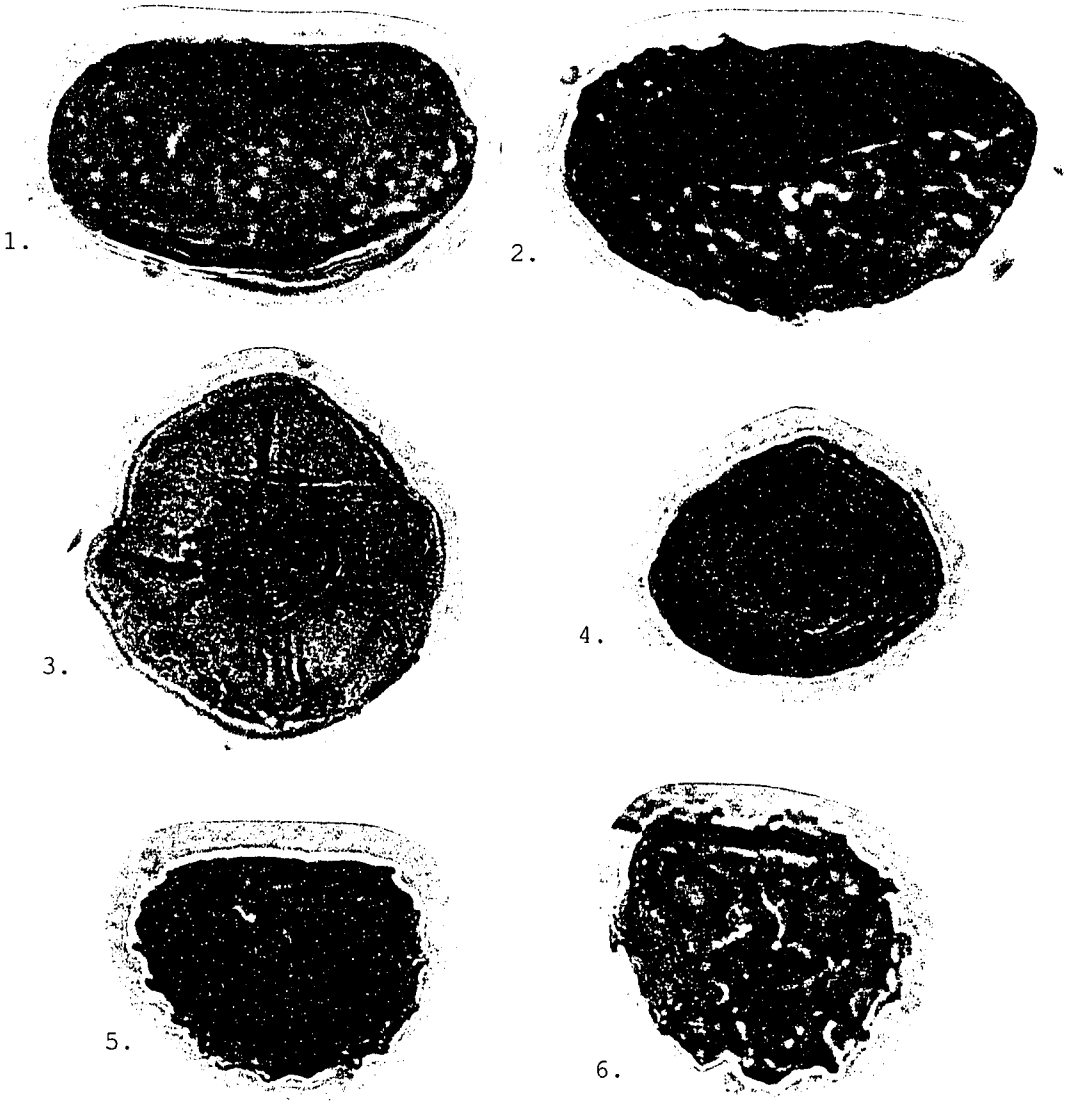
3. *Reticulatisporites dupliexinous* Brenner 1963: R13-6, ↓, 35U

4. *Cingutriletes clavus* (Balme) Dettmann 1963: R13-32, ↑, 14M

5. *Reticulisporites semireticulatus* (Burger) Norris 1967: R13-26, ↑, 10F

6. *Lycopodiumsporites crassimacerius* Hedlund 1966: R13-35, ↑, 16J

Plate 73



25 µm

Plate 74

Mazuma Creek Palynoflora
Florule C-4

Slide No. 94SR (MZ) C004

1. *Gleicheniidites circinidites* (Cookson) Brenner 1963: R13-15, ↓, 16V

2. *Biretisporites* sp. cf. *B. potoniaei* Delcourt and Sprumont 1955: R13-18, ↑, 2G

3. *Undulatisporites fossulatus* Singh 1971: R13-29, ↑, 13D

4. *Cyathidites australis* Couper 1953: R13-27, ↑, 11Q

5. *Camarozonosporites insignis* Norris 1967: R13-22, ↑, 6Q

6. *Verrucosisporites major* (Couper) Burden and Hills 1989: R13-7, ↓, 32-33W

Plate 74

25 μm

Plate 75

Mazuma Creek Palynoflora
Florule C-4

Slide No. 94SR (MZ) C004

1. *Cicatricosisporites* sp.: R13-25, ↑, 9-10S

2. *Cicatricosisporites* sp.: R13-33, ↑, 15G

3. *Interulobites* sp. cf. *I. intraverrucatus* Brenner 1963: R13-20, ↑, 6G

4. *Taurocuspidites segmentatus* Stover 1962: R13-13, ↓, 25W

Plate 75

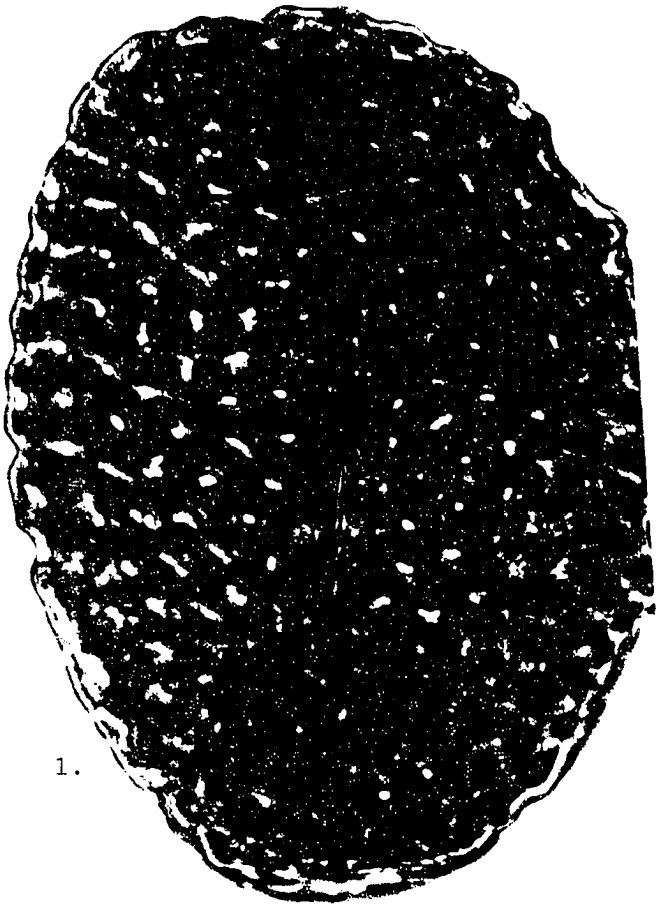
Plate 76

Mazuma Creek Palynoflora
Florule C-4

Slide No. 94SR (MZ) C004

1. *Foveasporis* sp. cf. F. linearis Krutzsch 1959: R13-19, ↑, 4-5R

Plate 76



1.

25 µm

Plate 77

Mazuma Creek Palynoflora
Florule C-4

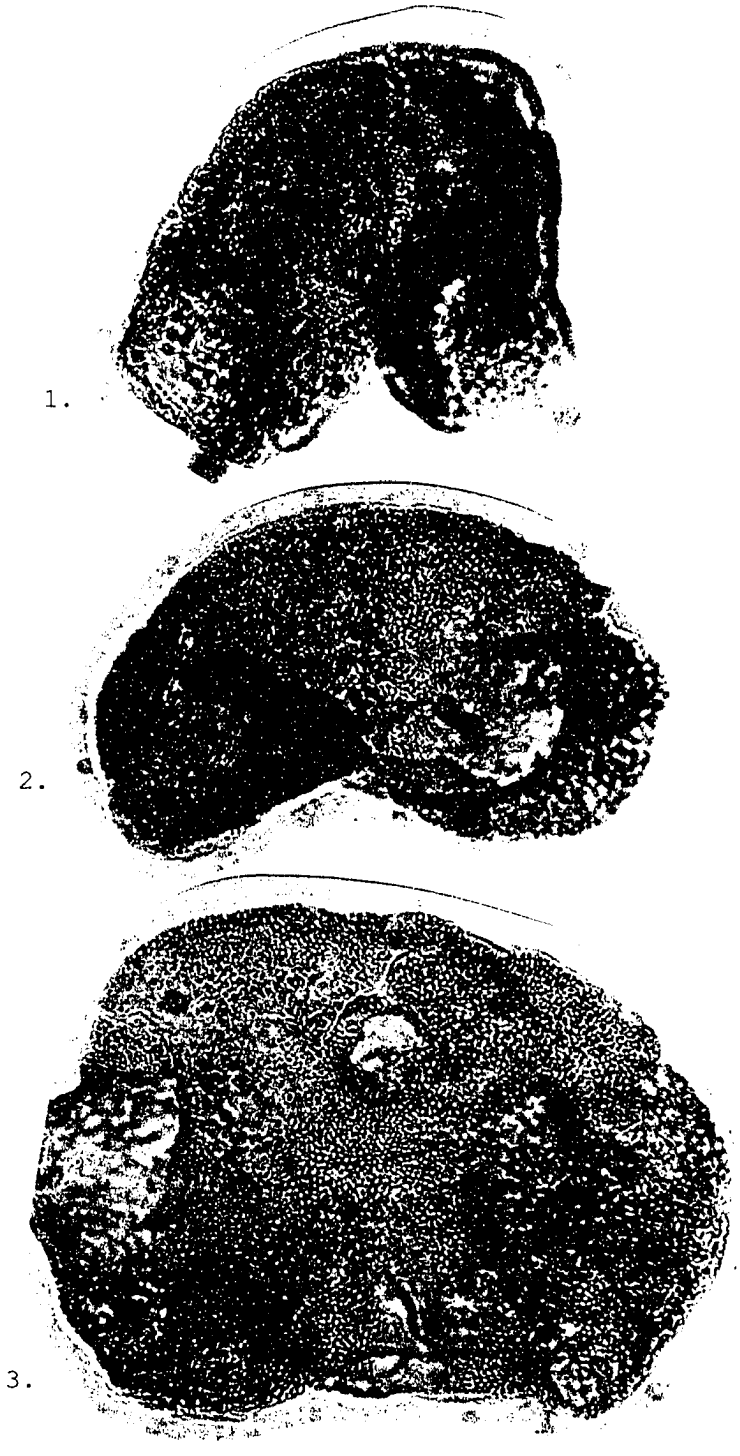
Slide No. 94SR (MZ) C004

1. *Abiespollenites* sp.: R13-4, ↓, 37H

2. *Abietineaepollenites microreticulatus* Groot and Penny 1960: R13-5, ↓, 37S

3. cf. *Parvisaccites amplus* Brenner 1963: R13-9, ↓, 23K

Plate 77



25 µm

Plate 78

Mazuma Creek Palynoflora
Florule C-4

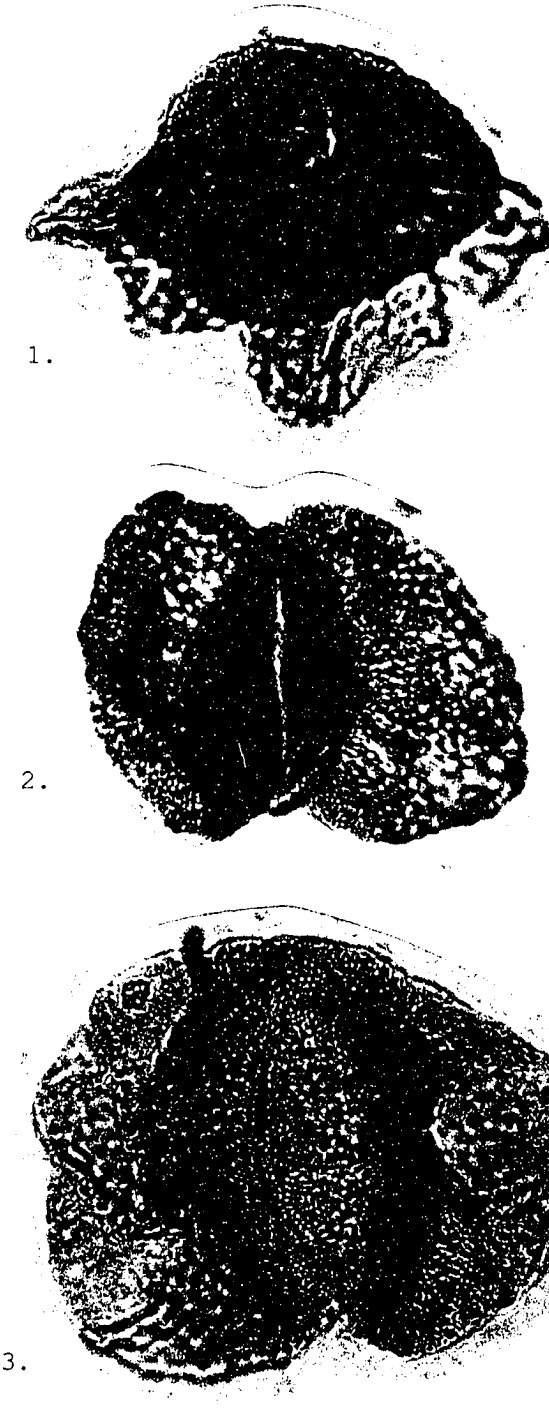
Slide No. 94SR (MZ) C004

1. *Podocarpidites granulatus* Singh 1971: R13-8, ↓, 32N

2. *Podocarpidites biformis* Rouse 1957: R13-16, ↑, 1J-K

3. *Podocarpidites minisculus* Singh 1964: R13-30, ↑, 13M

Plate 78



1.

2.

3.

25 µm

Plate 79

Mazuma Creek Palynoflora
Florule C-4

Slide No. 94SR (MZ) C004

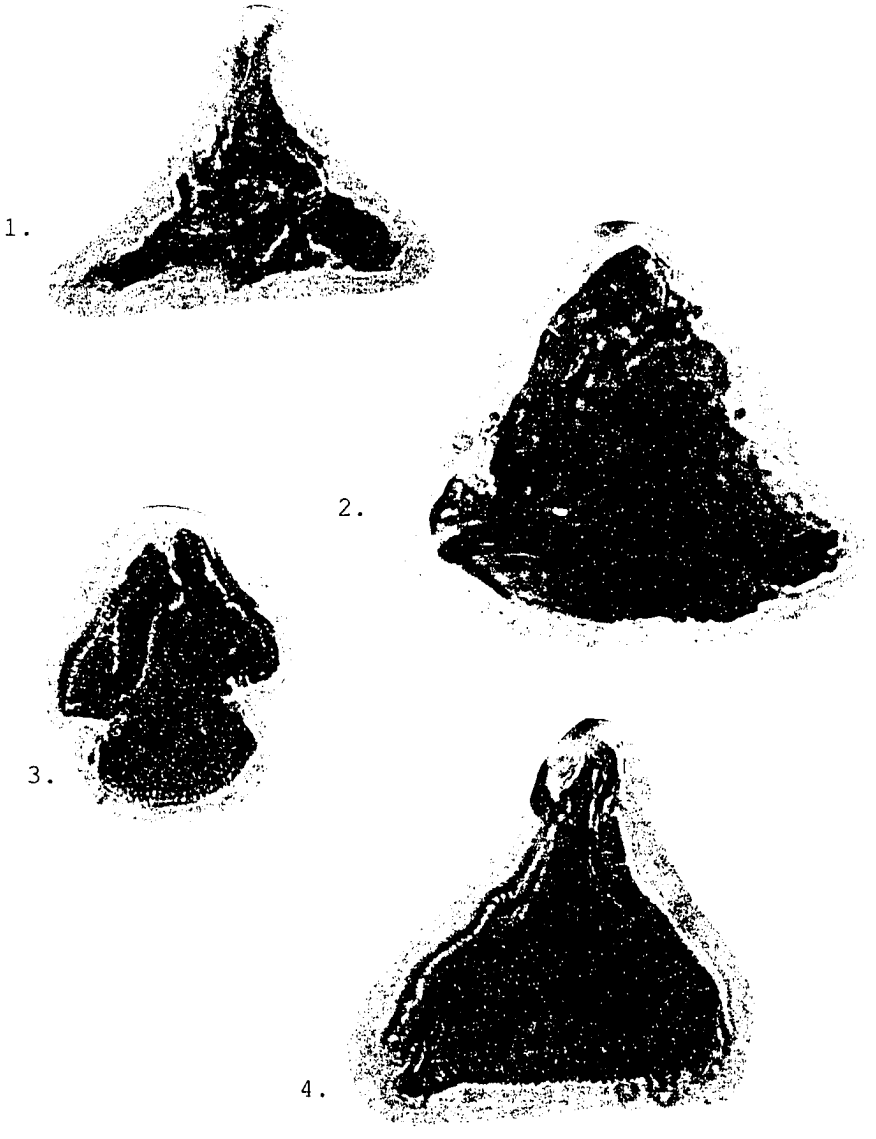
1. Unknown genus: R13-34, ↑, 15D

2. Unknown genus: R13-24, ↑, 7W

3. *Tricolpites* sp. cf. *T. parvus* Stanley 1965: R13-12, ↓, 25F

4. *Scollardia trapaformis* Srivastava 1966: R13-14, ↓, 25X

Plate 79



25 µm

Plate 80

Mazuma Creek Palynoflora
Florule C-5

Slide No. 94SR (MZ) C005

1. *Palambages canadiana* Srivastava 1968, fungal spore: R15-29, ↓, 37N

2. *Neoraistrickia truncata* (Cookson) Potonié 1956: R14-2, ↓, 27F

3. *Laevigatosporites* sp.: R14-30, ↑, 11H

4. *Stereisporites antiquasporites* (Wilson and Webster) Dettmann 1963: R14-23, ↑, 10B-C

5. *Lycopodiumsporites crassimacerius* Hedlund 1966: R14-11, ↓, 19K

6. *Deltoidospora hallii* Miner 1935: R14-8, ↓, 22K

7. *Rouseisporites triangularis* Pocock 1962: R14-3, ↓, 26Q

8. *Foraminisporis wonthaggiensis* (Cookson and Dettmann) Dettmann 1963: R14-5, ↓, 25V-26W

9. *Concavisporites* sp.: R14-24, ↑, 10Q

Plate 80

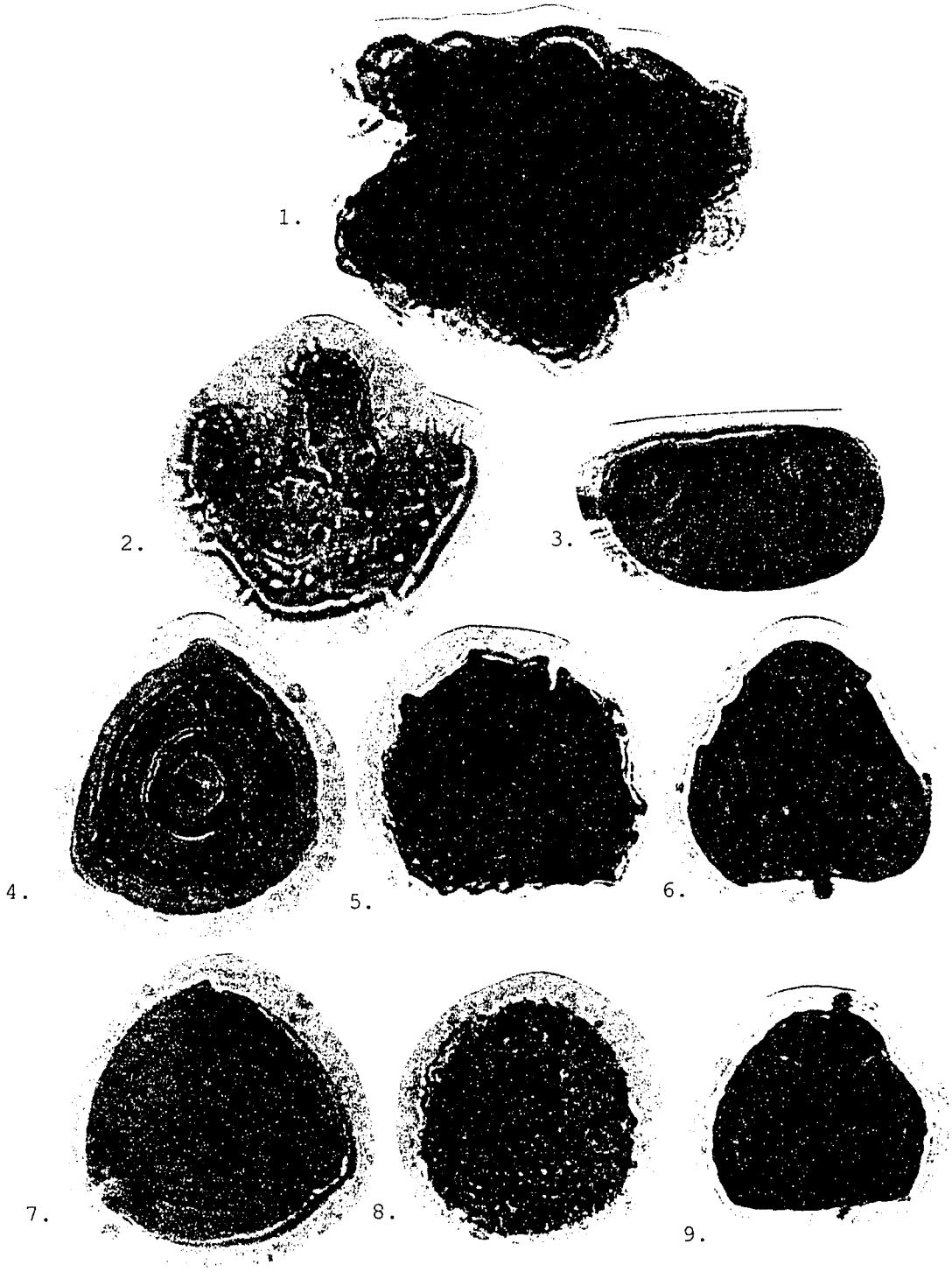


Plate 81

Mazuma Creek Palynoflora
Florule C-5

Slide No. 94SR (MZ) C005

1. *Camarozonosporites insignis* Norris 1967: R14-29, ↑, 11N

2. *Foveosporites* sp.: R14-33, ↑, 13E

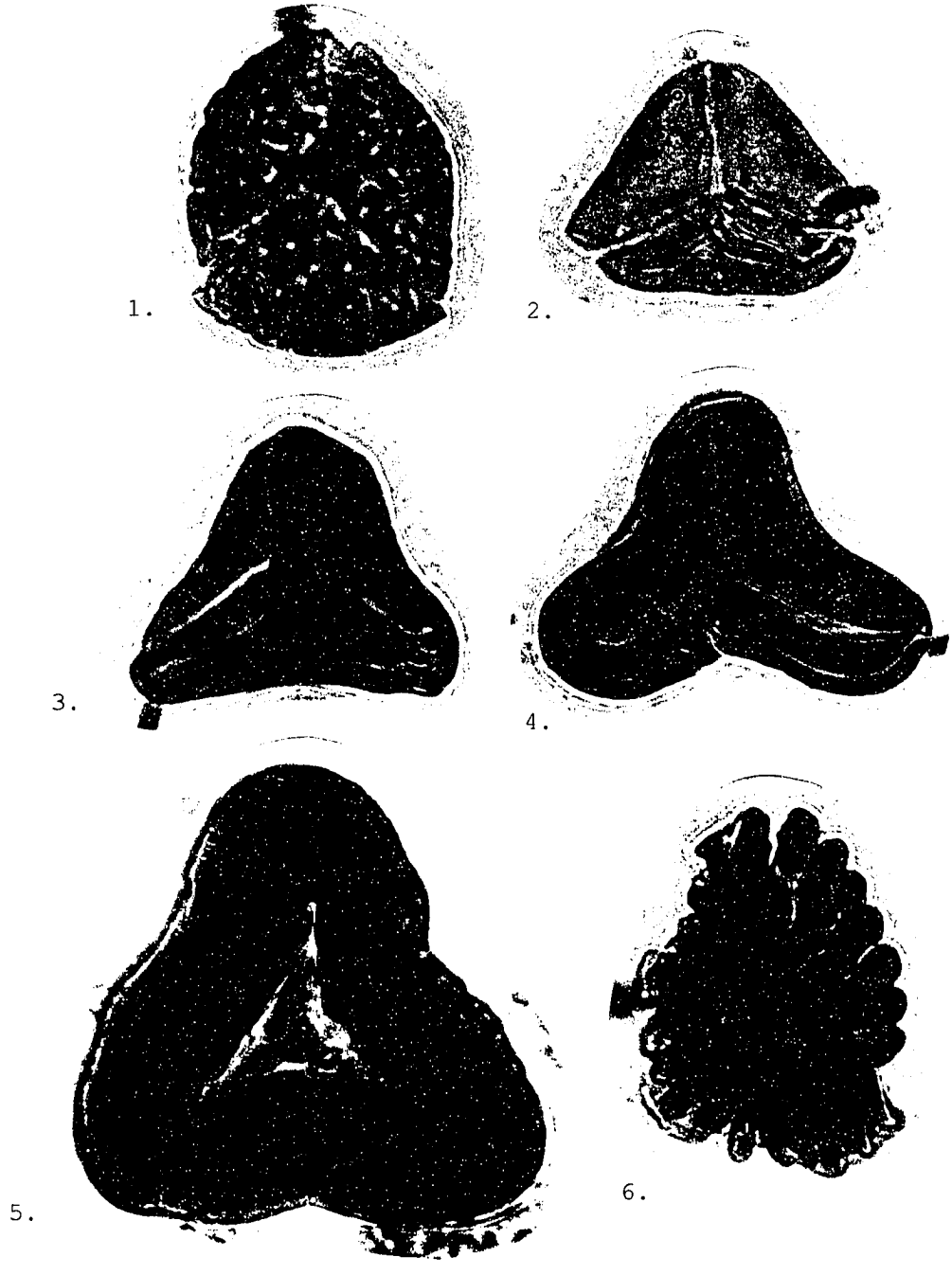
3. *Gleicheniidites senonicus* (Ross) Delcourt and Sprumont 1955: R14-35, ↑, 15Q

4. *Cyathidites minor* Couper 1953: R14-28, ↑, 11L

5. *Distaltriangulisporites perplexus* (Singh) Singh 1971: R14-32, ↑, 11-12S

6. *Cicatricosisporites* sp.: R14-16, ↑, 4L

Plate 81



25 µm

Plate 82

Mazuma Creek Palynoflora
Florule C-5

Slide No. 94SR (MZ) C005

1. *Hamulatisporis amplus* Stanley 1965: R15-35, ↓, 33J

2. *Verrucosisporites major* (Couper) Burden and Hills 1989: R15-36, ↓, 33J

3. *Camarozonosporites ambigens* (Fradkina) Playford 1971: R15-33, ↓, 36E

4. *Foveasporis* sp. cf. *F. linearis* Krutzsch 1959: R15-32, ↓, 36W

Plate 82

25 µm

Plate 83

Mazuma Creek Palynoflora
Florule C-5

Slide No. 94SR (MZ) C005

1. *Podocarpidites granulatus* Singh 1971: R14-25, ↑, 10Y

2. *P. granulatus*: R14-7, ↓, 22J

3. *Pinuspollenites* sp.: R14-34, ↑, 14S

4. *Cedripites canadensis* Pocock 1962: R14-6, ↓, 24D

5. *Podocarpidites potomacensis* Brenner 1963: R14-29, ↑, 10H

6. *Abietineaepollenites varius* Norton *in* Norton and Hall 1969: R14-31, ↑, 12D

Plate 83

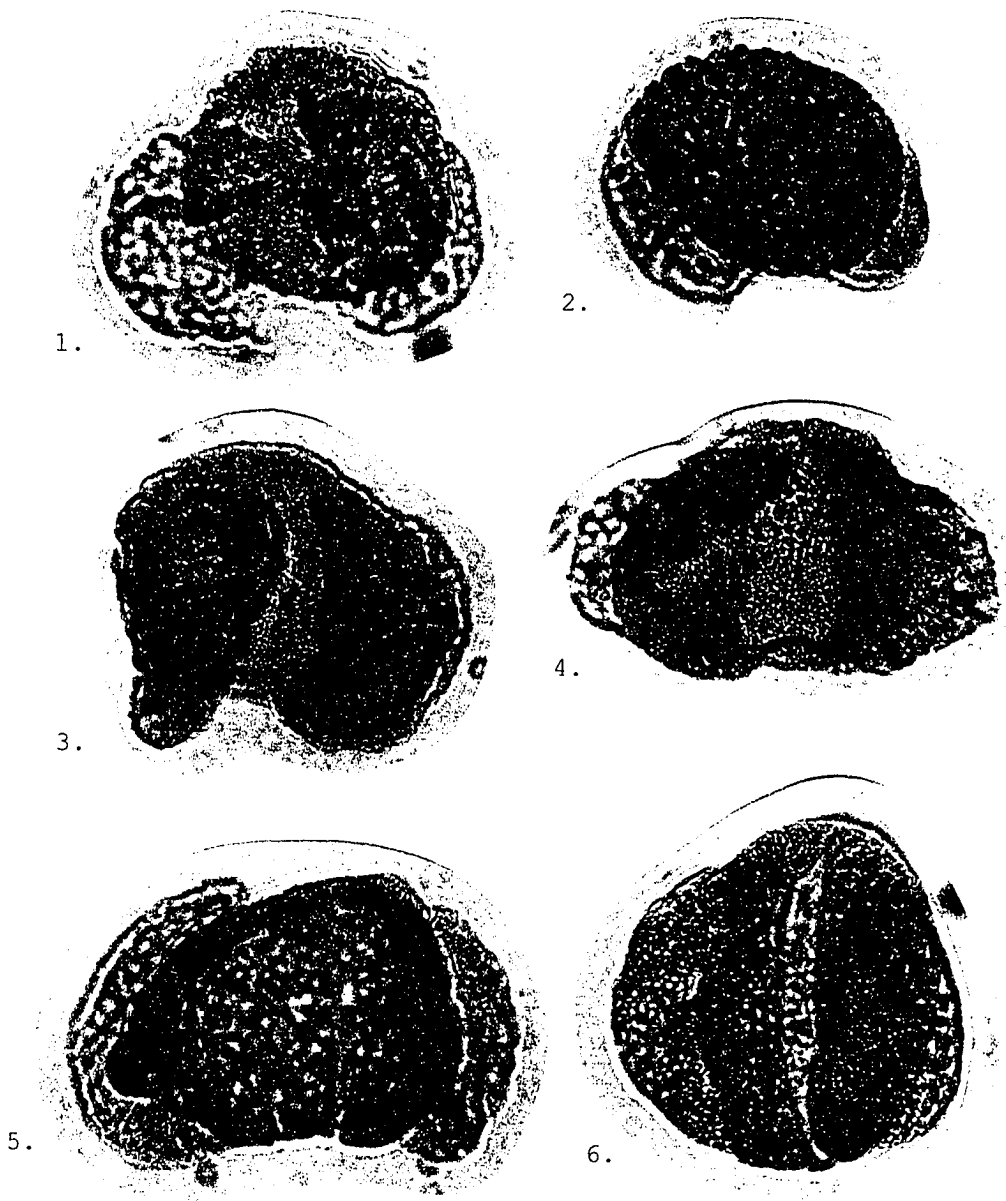


Plate 84

Mazuma Creek Palynoflora
Florule C-5

Slide No. 94SR (MZ) C005

1. *Abiespollenites* sp.: R14-4, ↓, 25N

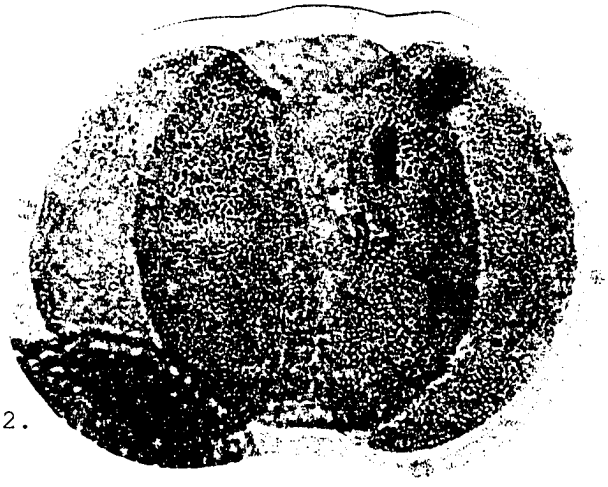
2. *Piceapollenites* sp.: R14-14, ↓, 16J

3. *Podocarpidites multesimus* (Bolkhovitina) Pocock 1962: R14-13, ↓, 17L

4. *Podocarpidites canadensis* Pocock 1962: R15-34, ↓, 35F

Plate 84

1.



2.

3.

4.

25 μm

Plate 85

Mazuma Creek Palynoflora
Florule C-5

Slide No. 94SR (MZ) C005

1. *Deltoidospora* sp.: R14-15, ↑, 3G

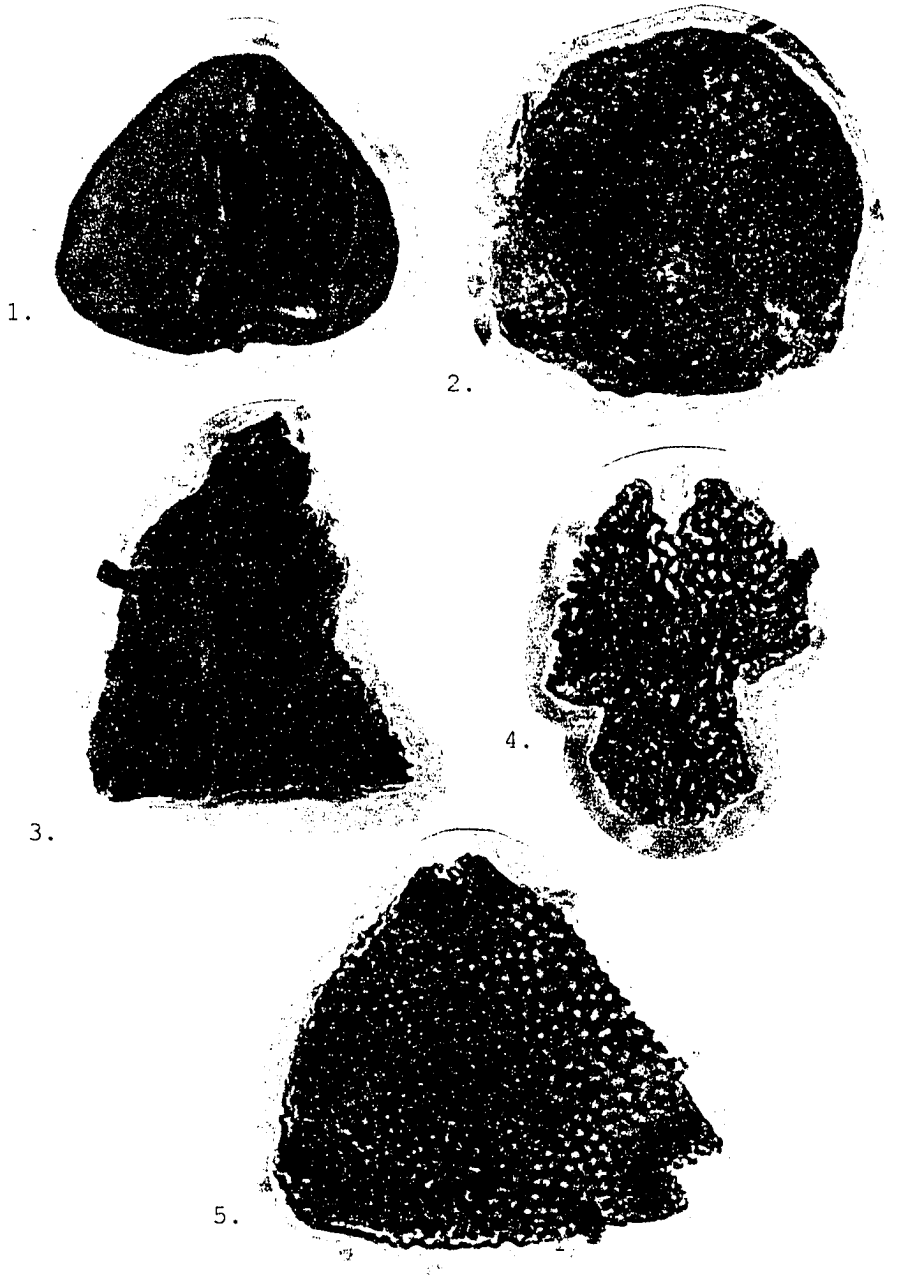
2. *Penetetrapites inconspicuus* Sweet 1986: R14-10, ↓, 21X

3. *Spermatites* sp.: R14-12, ↓, 17X

4. *Rousea subtilis* Srivastava 1970: R14-20, ↑, 6-7T

5. *Proteacidites auratus* Srivastava 1969: R14-22, ↑, 8S

Plate 85



25 μm

APPENDIX D
Photographic Plates

Plate 86

Mazuma Creek Palynoflora
Florules D-1, D-6

Slide No. 94SR (MZ) D006(2)

1. *Colligerites kutchensis* (Kar and Saxena) Jain and Kar 1979, fungal spore: D5-14, ↑, 8U

Slide No. 94SR (MZ) D006(1)

2. *Dyadosporites substrangulatus* (Salard-Cheboldaeff and Locquin) Kalgutar and Jansonius 2000, fungal spore: D5-34, ↓, 35U

Slide No. 94SR (MZ) D001(1)

3. *Fusiformisporites rugosus* Sheffy and Dilcher 1971, fungal spore: D1-28, ↓, 35K

4. *Pluricellaesporites sheffyi* Martinez-Hernandez and Tomasini-Ortiz 1989, fungal spore: D1-26, ↓, 3K

5. *Pluricellaesporites magnus* Rouse and Mustard 1997, fungal spore: D1-33, ↑, 15L

Plate 86

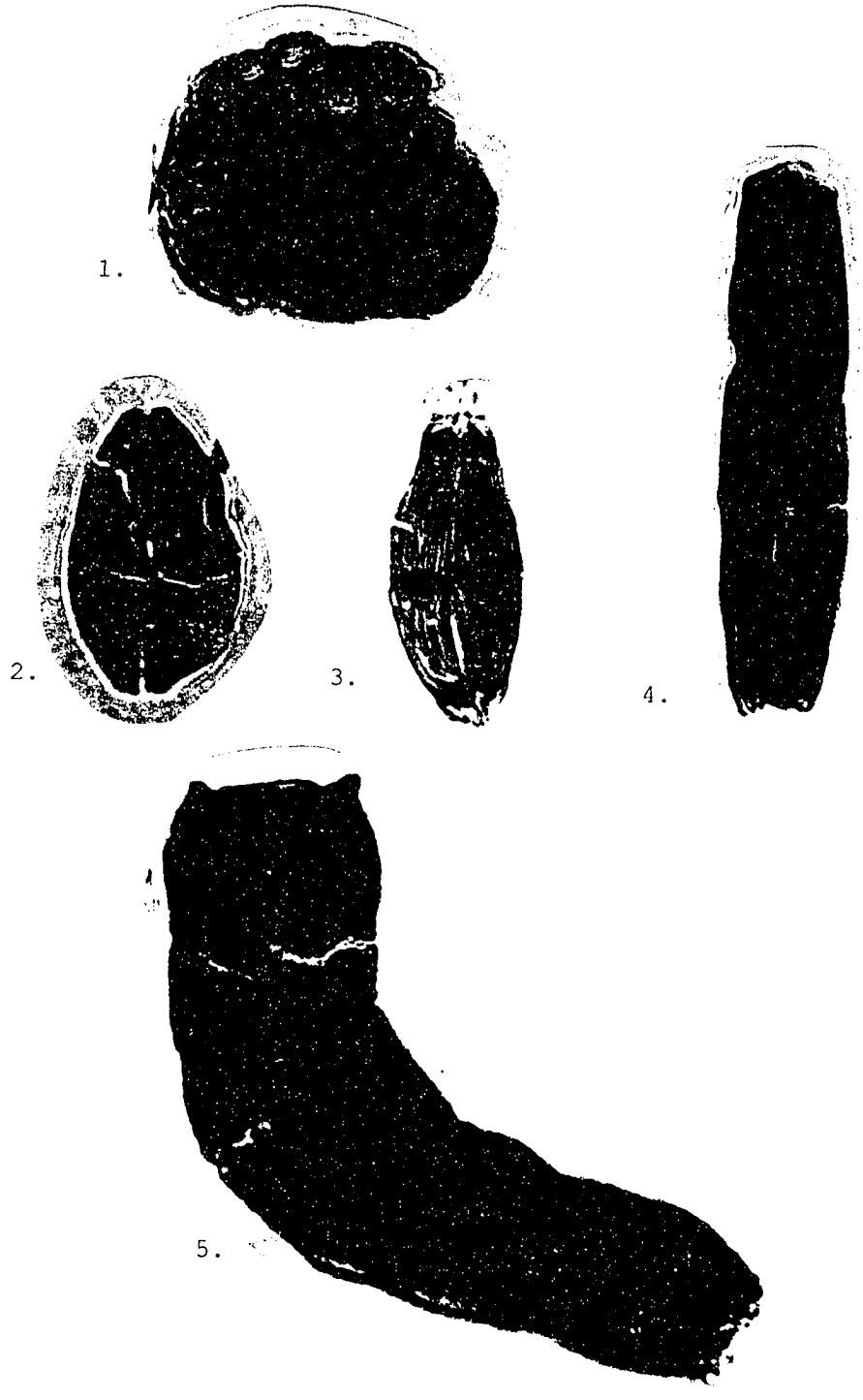


Plate 87

Mazuma Creek Palynoflora
Florules D-1, D-6

Slide No. 94SR (MZ) D001(1)
1. Wood: D1-31, ↑, 10-11R

Slide No. 94SR (MZ) D006(!)
2. Wood: D1-19, ↑, 2-3R

3. Wood: D1-20, ↑, 6-7W

4. Wood: D1-21, ↑, 12V

5. Wood: D1-24, ↑, 8F

Slide No. 94SR (MZ) D006(2)
6. Wood cell: D1-18, ↑, 14T

Slide No. 94SR (MZ) D001(1)
7. Wood: D1-29, ↓, 31L

Plate 87

25 µm

Plate 88

Mazuma Creek Palynoflora
Florules D-6, D-12

Slide No. 94SR (MZ) D006(2)
1. Wood: D1-13, ↑, 6-7S

Slide No. 94SR (MZ) D0012(1)
2. Wood: D1-9, ↑, 7D-E

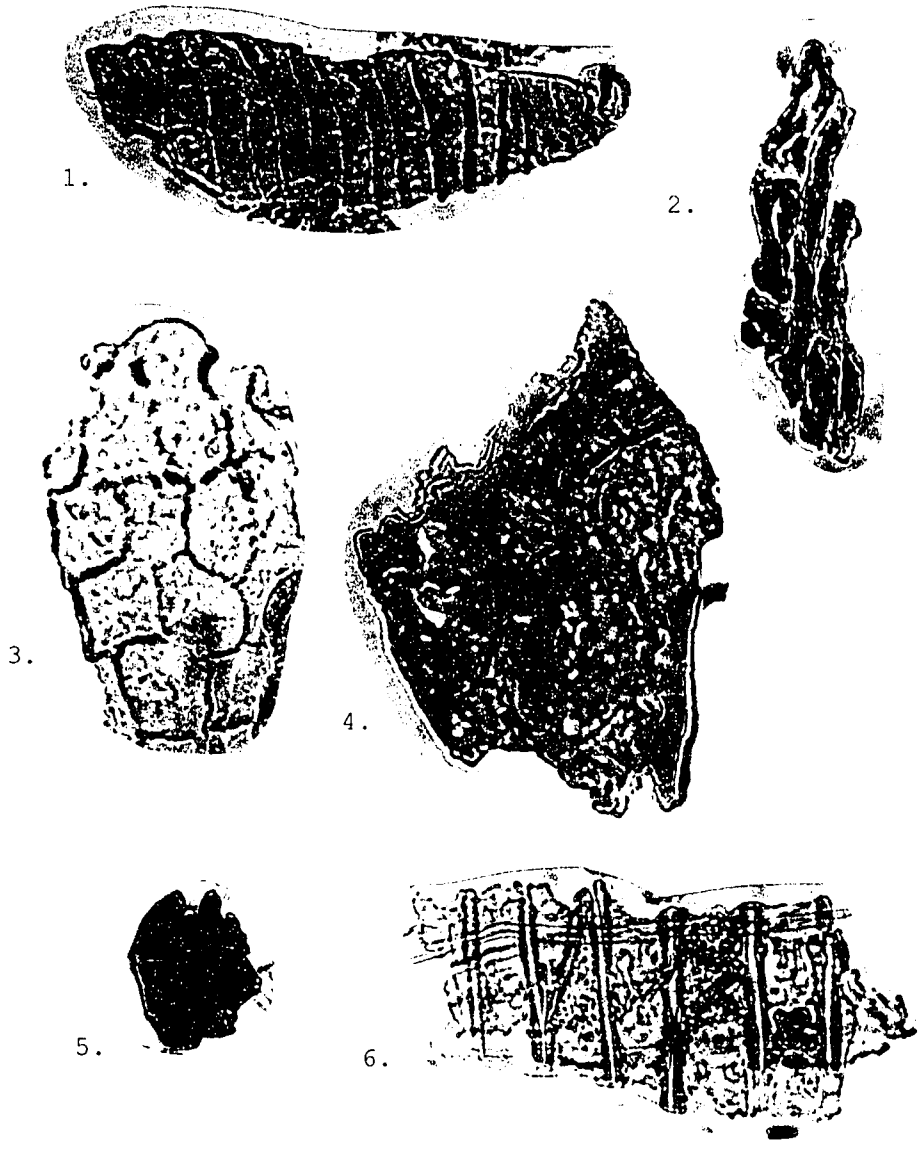
3. Wood: D1-8, ↑, 6-7T

4. Wood: D1-7, ↓, 5D

5. Wood: D1-4, ↓, 31-32N

Slide No. 94SR (MZ) D0012(2)
6. cf. *Pinus* Tidwell 1998: D1-3, ↑, 17K

Plate 88



25 µm

Plate 89

Mazuma Creek Palynoflora
Forule D-1

Slide No. 94SR (MZ) D001(1)

1. *Foveosporites subtriangularis* (Brenner) Doring 1966: D2-32, ↓, 34V

Slide No. 94SR (MZ) D001(2)

2. *Cicatricosisporites ornatus* Srivastava 1972: D2-30, ↑, 12-13N

Slide No. 94SR (MZ) D001(1)

3. *Baculatisporites* sp.: D2-36, ↑, 12Q-R

4. *Undulatisporites fossulatus* Singh 1971: D2-34, ↓, 28K

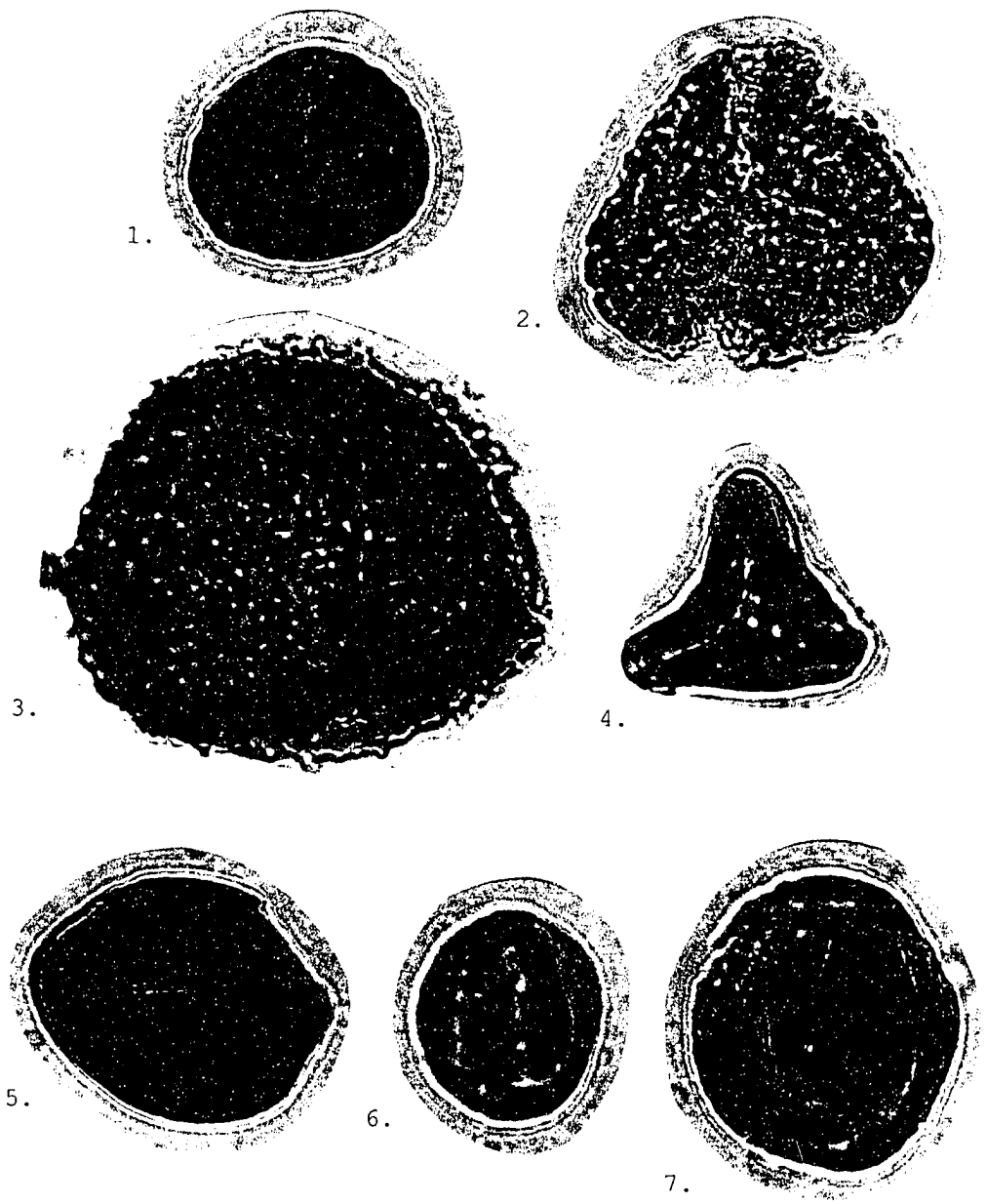
5. *Eucommiidites troedssonii* Erdtman 1948: D2-33, ↓, 29R-S

6. *Eucommiidites minor* Groot and Penny 1960: D2-35, ↓, 26R

Slide No. 94SR (MZ) D001(2)

7. cf. *Nyssoidites anulatus* (Chlonova) Sweet 1986: D2-29, ↑, 12R

Plate 89



25 µm

Plate 90

Mazuma Creek Palynoflora
Florule D-4

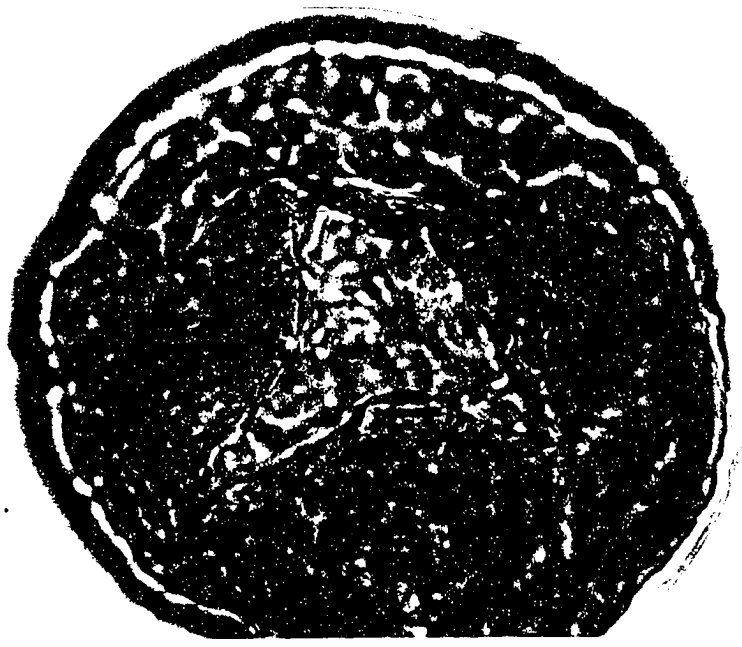
Slide No. 94SR (MZ) D004(1)

1. *Lycopodiacidites canaliculatus* Singh 1971: D2-6, ↑, 10Q

2. *Calamospora* sp.: D2-3, ↑, 8-9U

Plate 90

1.



2.

25 μm

Plate 91

Mazuma Creek Palynoflora
Florule D-4

Slide No. 94SR (MZ) D004(1)

1. *Camarozonitesporites insignis* Norris 1967: D2-15, ↑, 14G-H

2. *Cyathidites minor* Couper 1953: D2-27, ↑, 19T

3. *Deltoidospora hallii* Miner 1935: D2-23, ↑, 18W

4. *Foveosporites* sp.: D2-20, ↑, 15F-G

5. *Gleicheniidites circinidites* (Cookson) Brenner 1963: D2-24, ↑, 18S

6. *Deltoidospora* sp.: D2-26, ↑, 9P

Plate 91

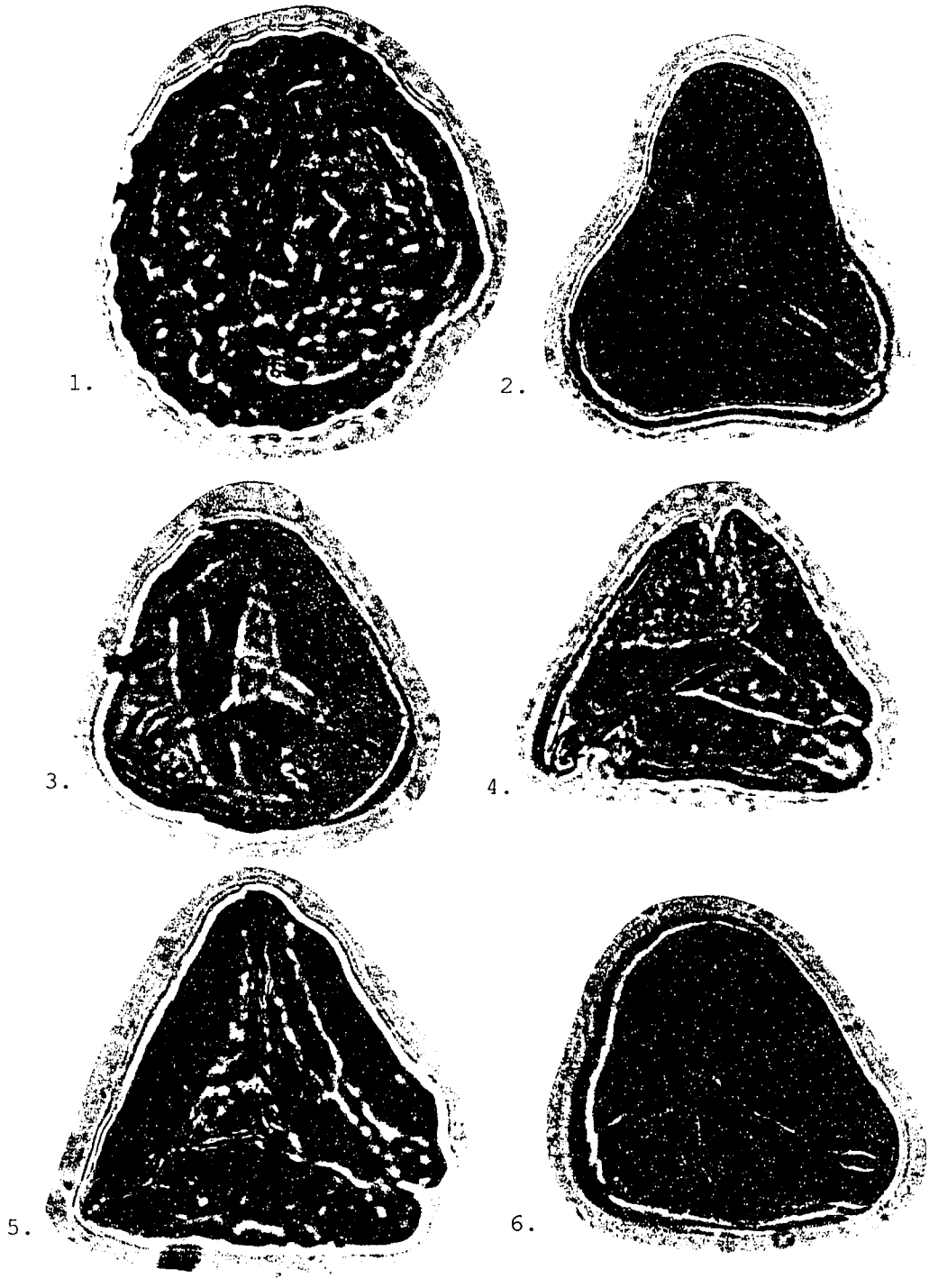


Plate 92

Mazuma Creek Palynoflora
Florule D-4

Slide No. 94SR (MZ) D004(1)

1. *Cicatricosisporites* sp.: D2-16, ↑, 14-15V

2. *Polycingulatisporites reduncus* (Bolkhovitina) Playford and Dettmann 1965: D2-2, ↑, 8G

3. *Distaltriangulisporites perplexus* (Singh) Singh 1971: D2-37, ↑, 16-17G

Plate 92

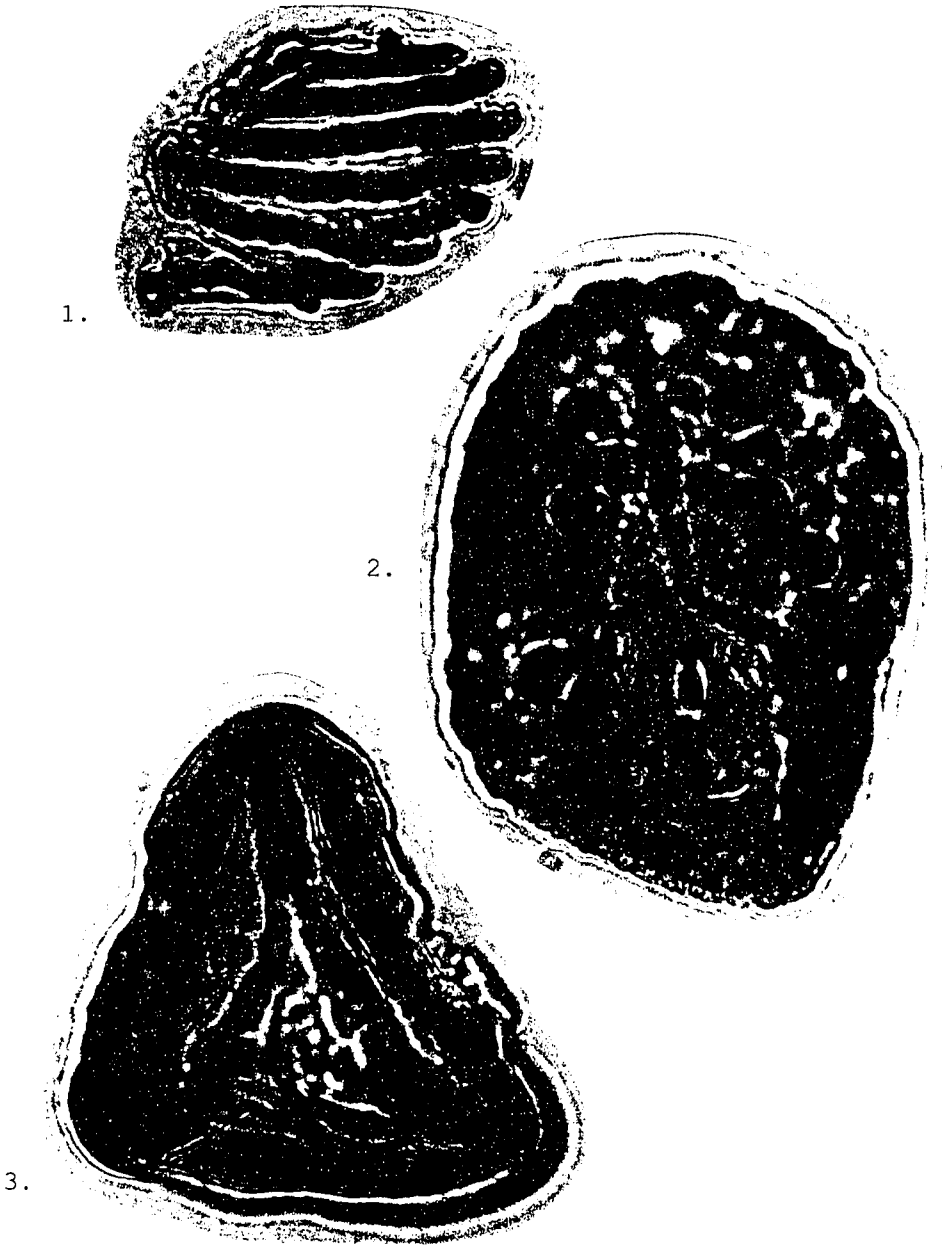


Plate 93

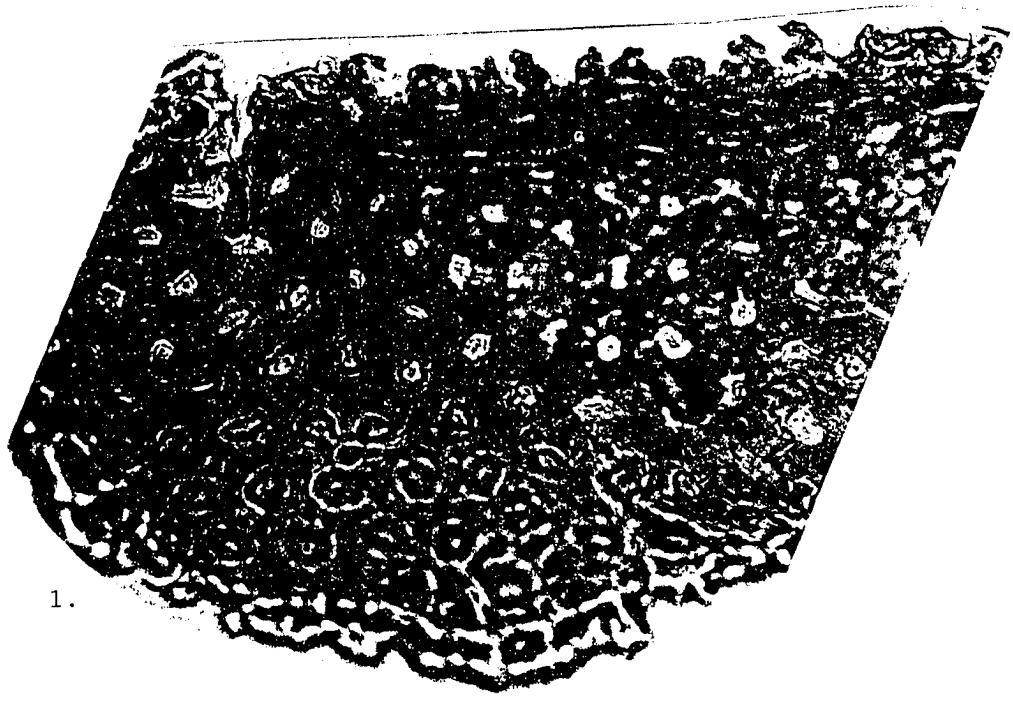
Mazuma Creek Palynoflora
Florule D-4

Slide No. 94SR (MZ) D004(1)

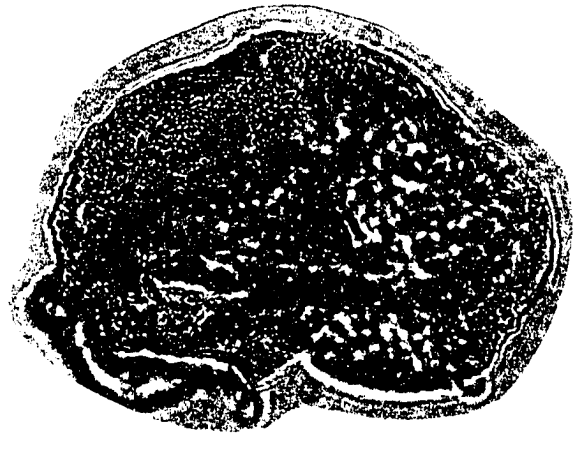
1. *Schizaea reticulata* Cookson 1956: D2-9, ↑, 11-12U

2. *Abiespollenites* sp.: D2-14, ↑, 13P

Plate 93



1.



2.

25 µm

Plate 94

Mazuma Creek Palynoflora
Florule D-4

Slide No. 94SR (MZ) D004(1)

1. *Extraporopollenites* sp.: D2-22, ↑, 16R-S

2. *Reticolpites vulgaris* Pierce 1961: D2-13, ↑, 13Q

3. *Spermatites* sp.: D2-8, ↑, 10-11G

4. *Retitricolpites maximus* Singh 1971: D2-10, ↑, 11-12H

5. *Cranwellia striata* (Couper 1953) Srivastava 1966: D2-7, ↑, 10Q

6. *Proteacidites auratus* Srivastava 1969: D2-1, ↑, 8G

Plate 94

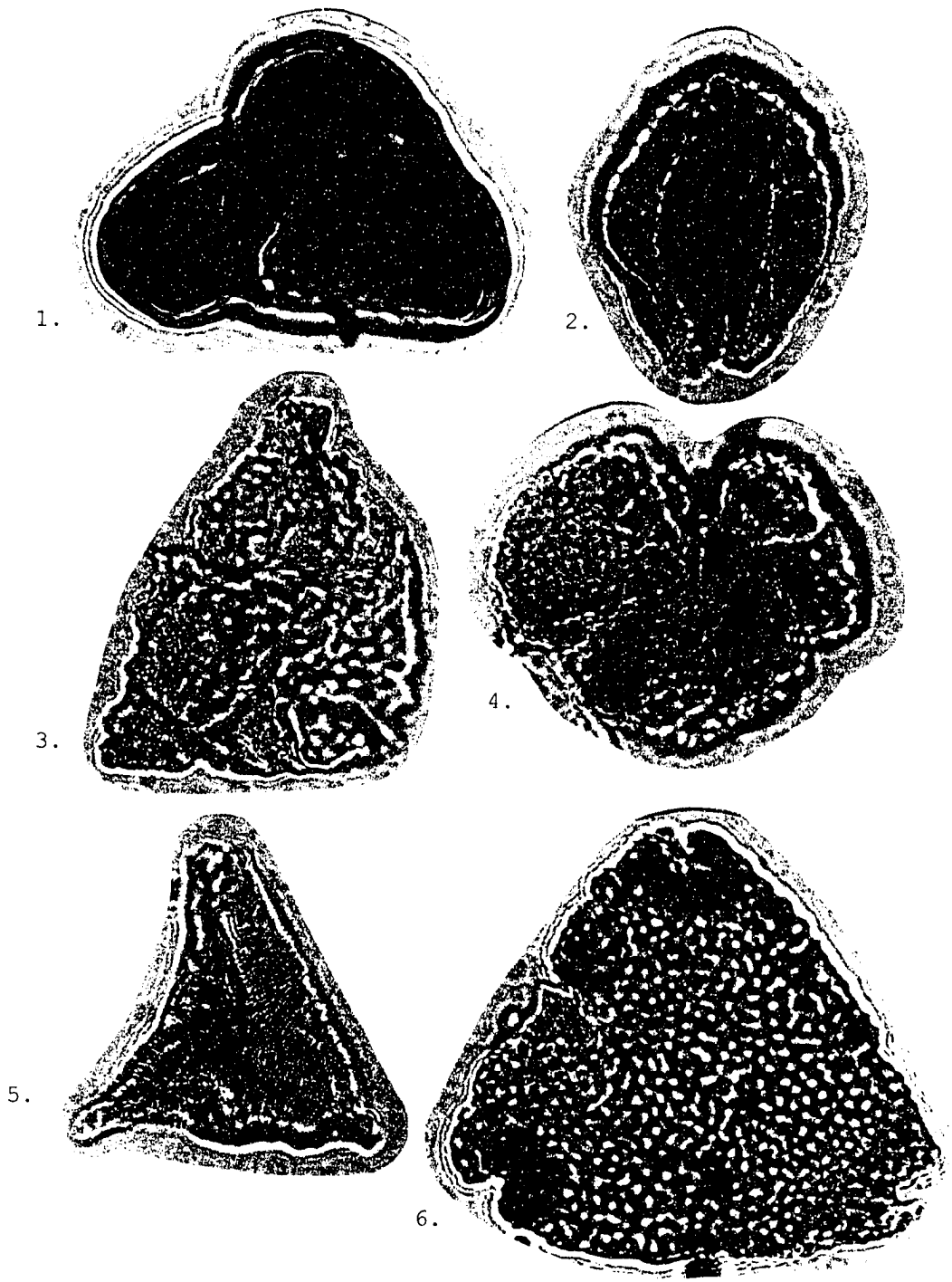


Plate 95

Mazuma Creek Palynoflora
Florule D-4

Slide No. 94SR (MZ) D004(1)

1. *Laevigatosporites* sp.: D3-29, ↓, 20M

2. *Retitriletes austroclavatidites* (Cookson) Krutzsch 1963: D3-23, ↓, 29U

3. *Baculatisporites comaumensis* (Cookson) Potonié 1956: D3-32, ↑, 3-4F

4. *Converrucosporites* sp.: D3-16, ↓, 33P

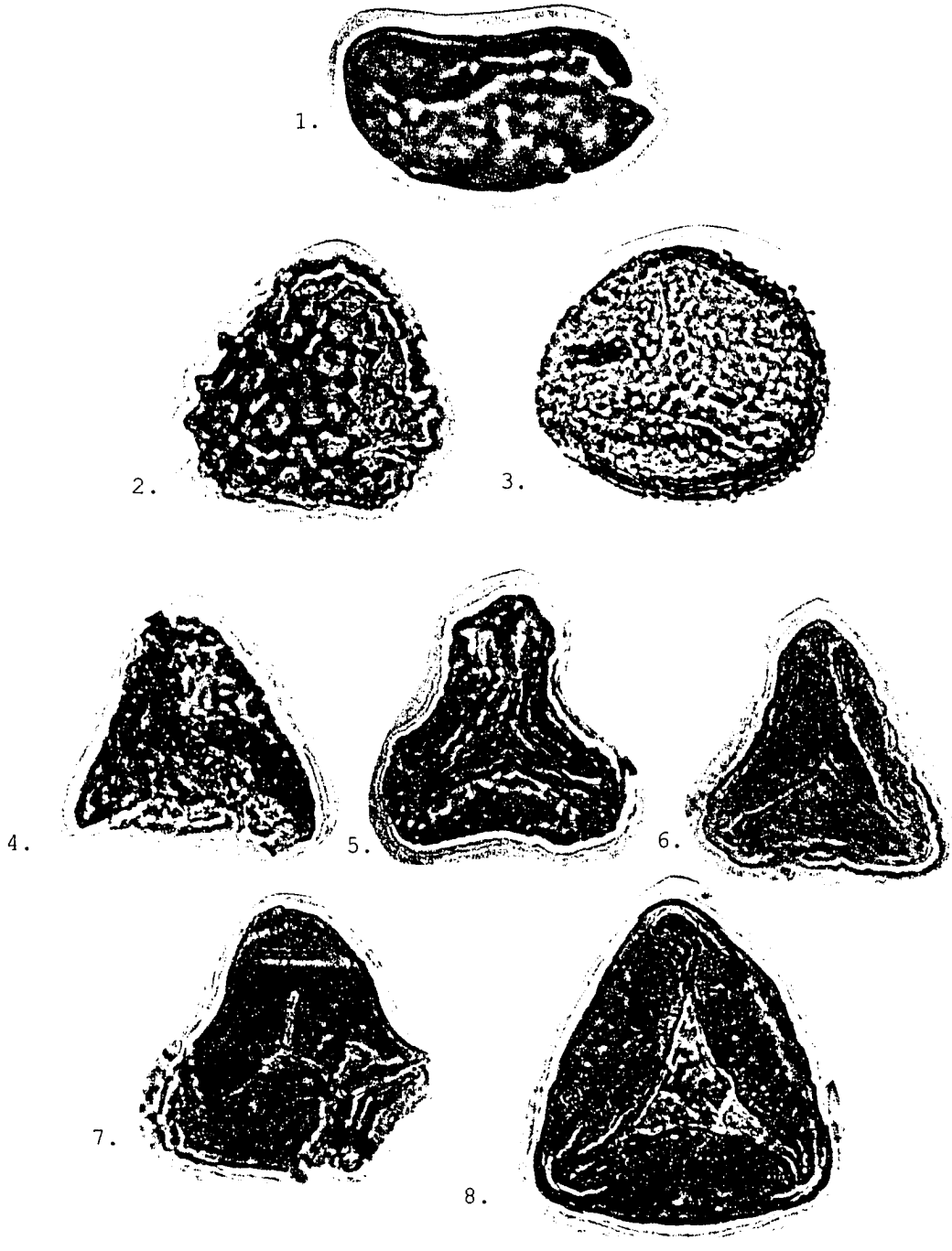
5. *Gleicheniidites* sp cf. *G. senonicus* (Ross) Delcourt and Sprumont 1955: D3-22, ↓, 29T-U

6. *Gleicheniidites circinidites* (Cookson) Brenner 1963: D3-28, ↓, 32P

7. *Deltoidospora juncta* (Kara-Murza) Singh 1964: D3-19, ↓, 32V

8. *Deltoidospora* sp.: D3-35, ↑, 7N-P

Plate 95



25 µm

Plate 96

Mazuma Creek Palynoflora
Florule D-4

Slide No. 94SR (MZ) D004(1)

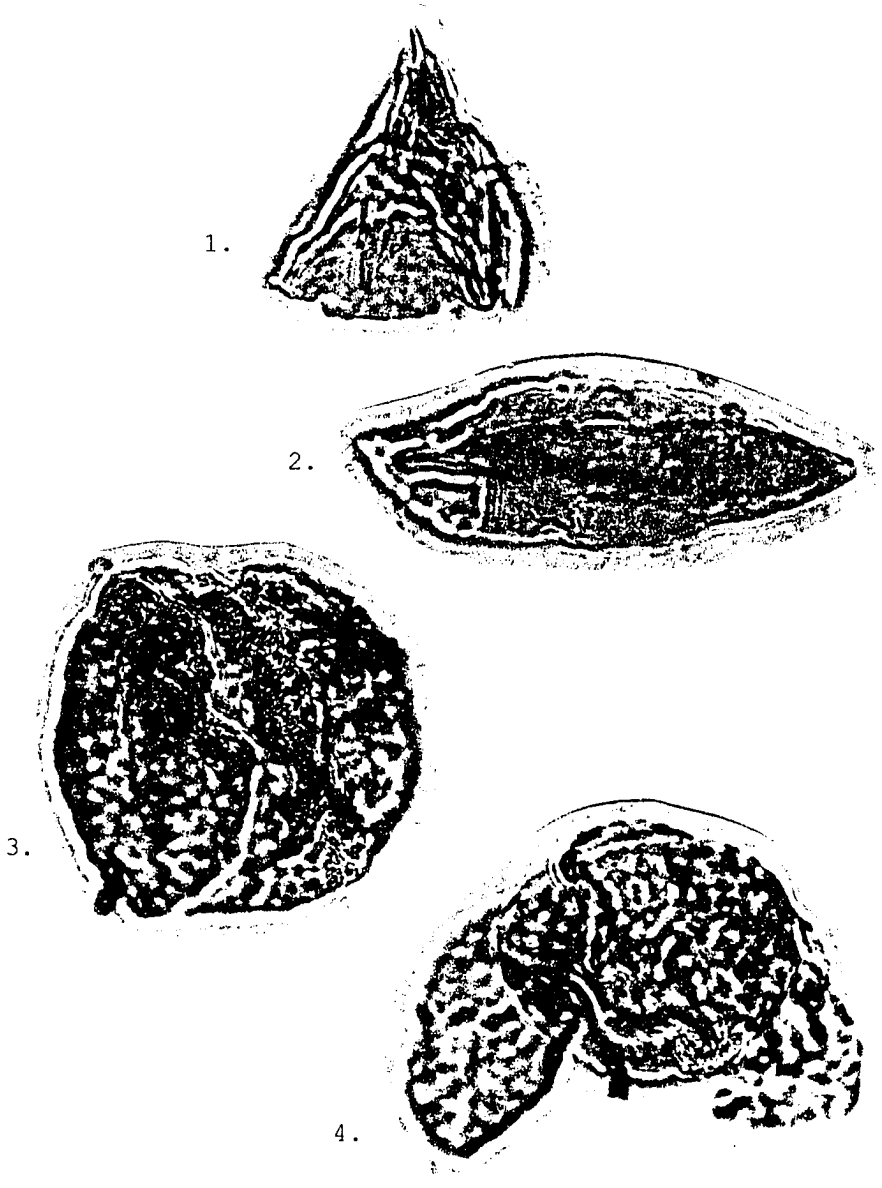
1. cf. *Duplosporis ocliferius* (Cholnova) Bondarenko 1965: D3-17, ↓, 33T

2. *Ephedrapites* sp.: D3-20, ↓, 29-30K

3. *Podocarpidites multesimus* (Bolkhovitina) Pocock 1962: D3-31, ↑, 3T

4. *Podocarpidites* sp. cf. *P. ellipticus* Cookson 1947: D3-13, ↓, 35K

Plate 96



25 μm

Plate 97

Mazuma Creek Palynoflora
Florule D-4

Slide No. 94SR (MZ) D004(1)

1. *Liliacidites inaequalis* Singh 1971: D3-21, ↓, 29R-S

2. *Betulaepollenites* sp.: D3-18, ↓, 33T

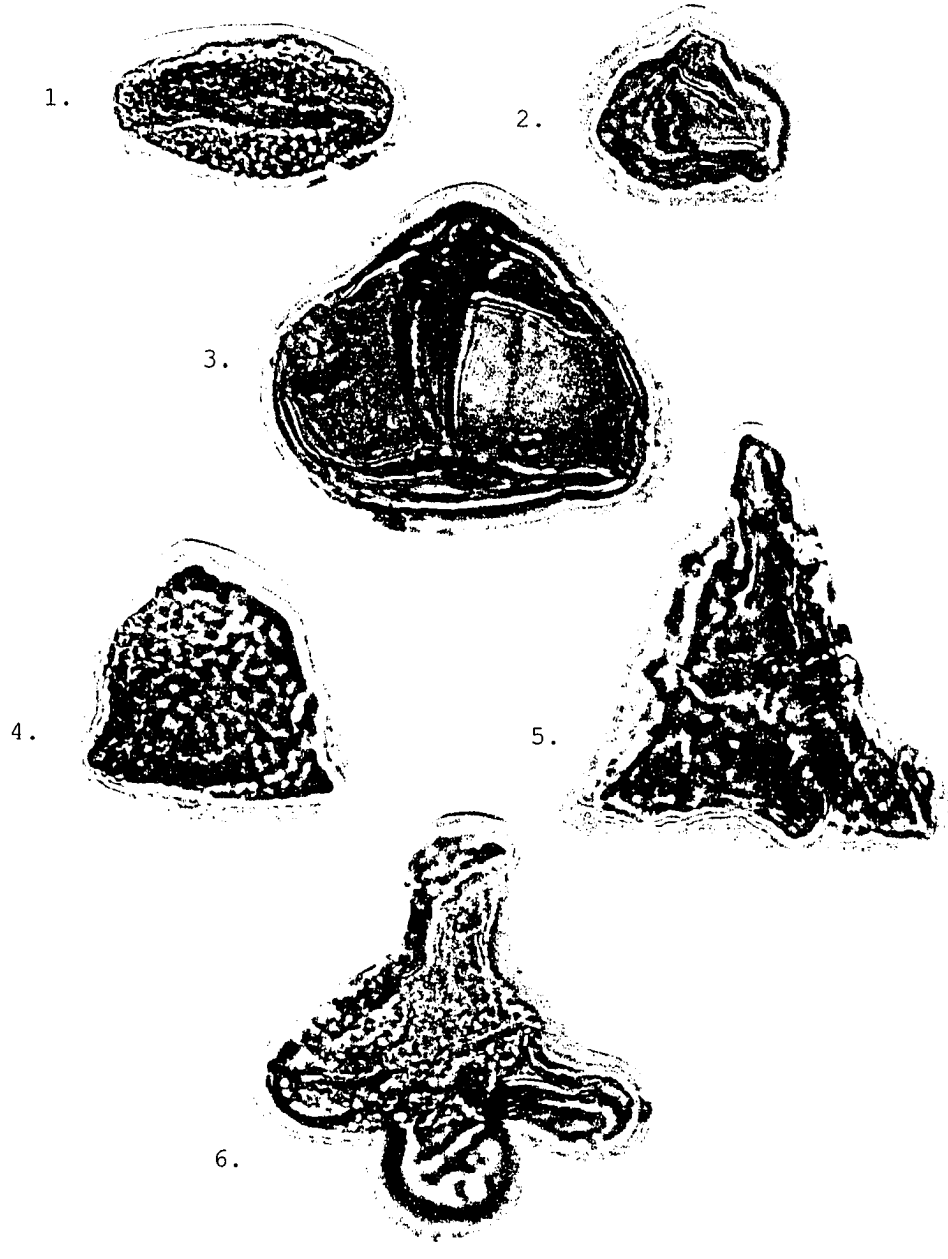
3. *Extraporopollenites* sp.: D3-33. ↑, 3-4F

4. cf. *Penetetrapites inconspicuous* Sweet 1986: D3-15, ↓, 33-34K

5. Unknown genus: D3-36, ↑, 8R

6. *Aquilapollenites* sp.: D3-30, ↑, 1C

Plate 97



25 μm

Plate 98

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(1)

1. *Retitriletes austroclavatidites* (Cookson) Krutzsch 1963: D4-20, ↓, 17M

Slide No. 94SR (MZ) D006(2)

2. *Selaginella simplex* Krasnova *in* Samoilovitch and Mchedlishvili 1961: D5-20, ↑, 13P

Slide No. 94SR (MZ) D006(1)

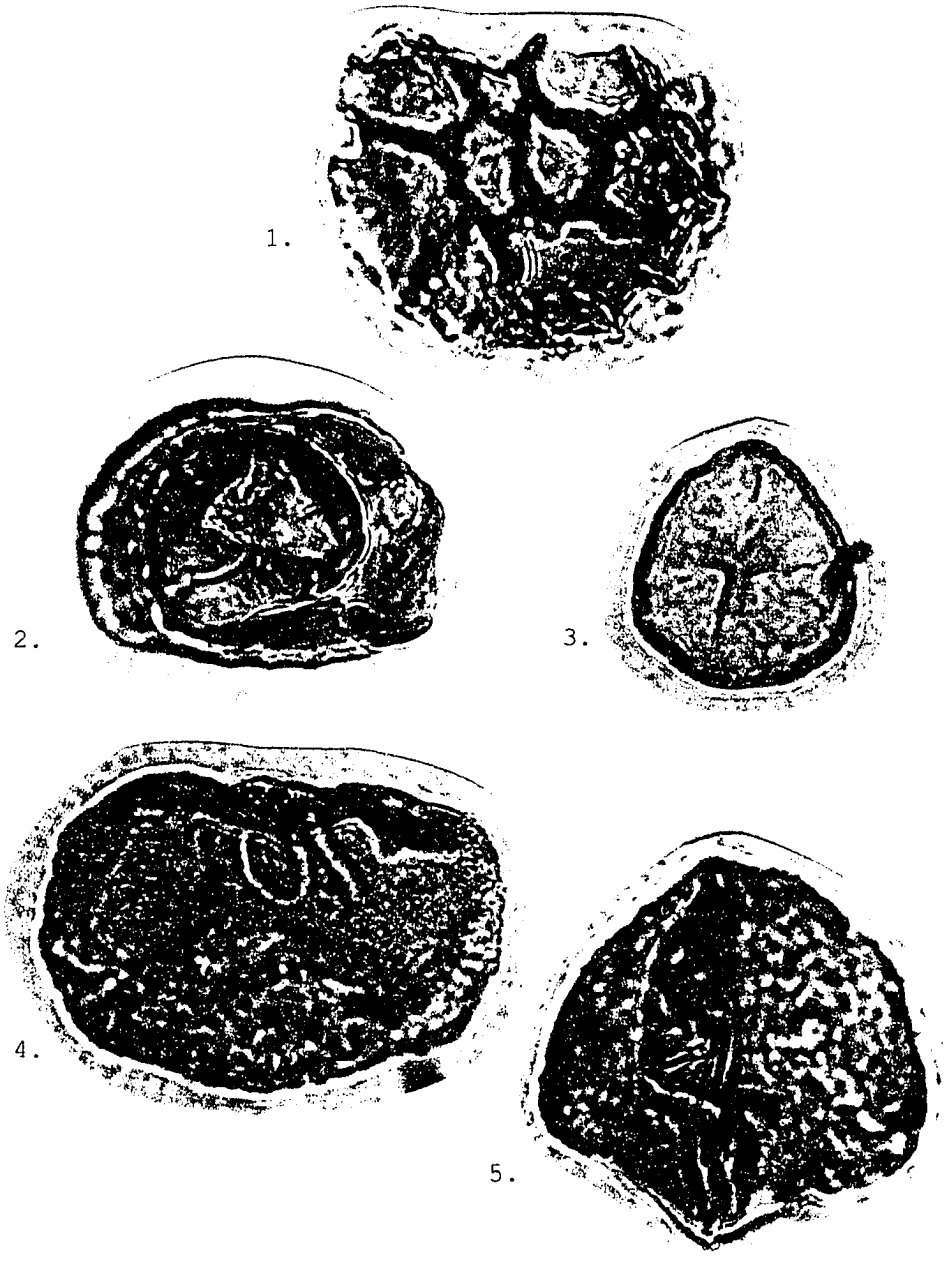
3. *Stereisporites antiquasporites* (Wilson and Webster) Dettmann 1963: D4-2, ↓, 34L

Slide No. 94SR (MZ) D006(2)

4. *Psilatriletes radiatus* (Brenner) Doring 1966: D5-28, ↑, 19-20G

5. *Deltoidospora neddeni* (Potonié) Orbell 1973: D4-34, ↑, 12-13K

Plate 98



25 µm

Plate 99

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(1)

1. *Ornamentifera baculata* Singh 1971: D4-13, ↓, 24H

2. *O. baculata*: D4-17, ↓, 20U

Slide No. 94SR (MZ) D006(2)

3. *Baculatisporites comaumensis* (Cookson) Delcourt and Sprumont 1955: D5-23, ↑, 18Q

4. cf. *Pilosisporites trichopapillosus* (Thiergart) Potonié 1956: D5-8, ↑, 4H-5J

Slide No. 94SR (MZ) D006(1)

5. *Retitriletes singhii* Srivastava 1972: D3-5, ↑, 19-20K

Slide No. 94SR (MZ) D006(2)

6. *Osmundacidites wellmanii* Couper 1953: D5-25, ↑, 19P

Plate 99

25 µm

Plate 100

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(1)

1. *Foveosporites* sp.: D4-1, ↓, 35R

2. *Triancoraeosporites reticulatus* Schulz 1962: D4-7, ↓, 31H

3. *Cornutisporites seebergensis* Schultz 1962: D3-11, ↑, 19-20S

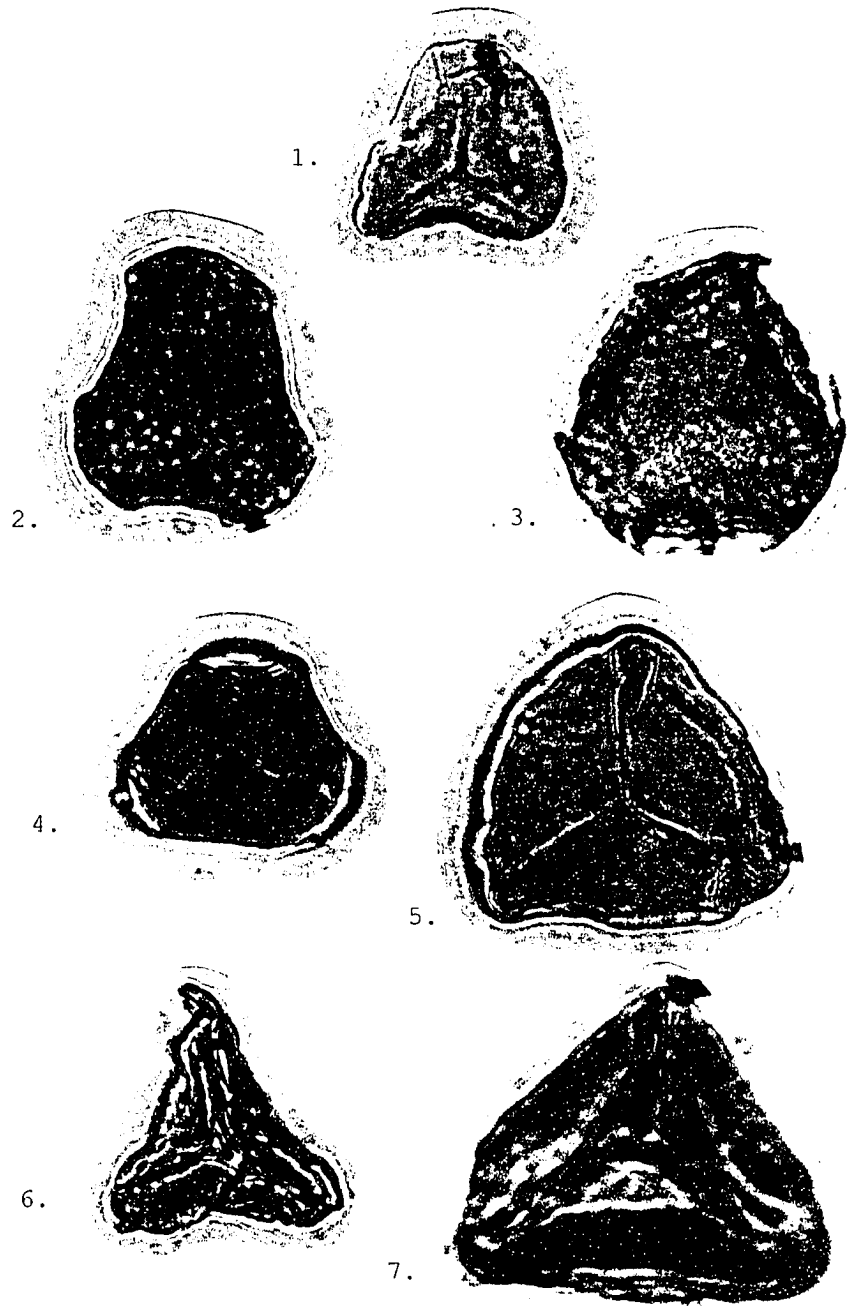
4. *Deltoidospora juncta* (Kara-Murza) Singh 1964: D4-16, ↓, 21H

5. *Biretisporites potoniaei* Delcourt and Sprumont 1955: D4-27, ↑, 5R

6. Unknown genus: D4-10, ↓, 25-26H

7. *Gleicheniidites senonicus* (Ross) Delcourt and Sprumont 1955: D3-6, ↑, 19E-20F

Plate 100



25 μm

Plate 101

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(2)

1. *Cyathadites australis* Couper 1953: D5-13, ↑, 8T-U

2. *C. australis*: D5-12, ↑, 8R-S

3. *Camarozonosporites insignis* Norris 1967: D5-9, ↑, 5N

4. *Taurocuspidites segmentatus* Stover 1962: D3-4, ↑, 18-19R

Plate 101

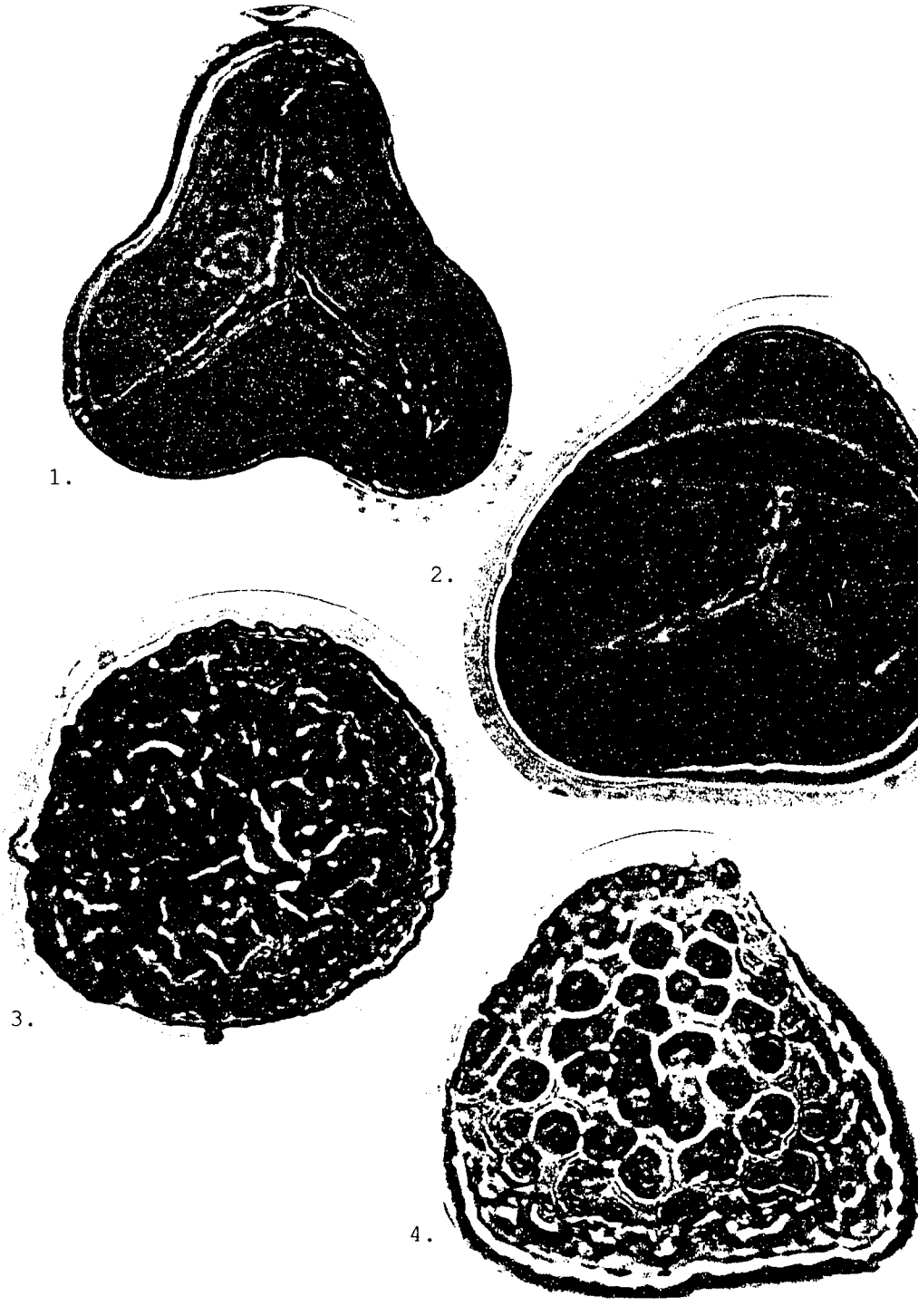


Plate 102

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(1)

1. *Cicactricosisporites* sp.: D4-28, ↑, 6D

2. *Cicatricosisporites hughesi* Dettmann 1963: D4-23, ↑, 3Q

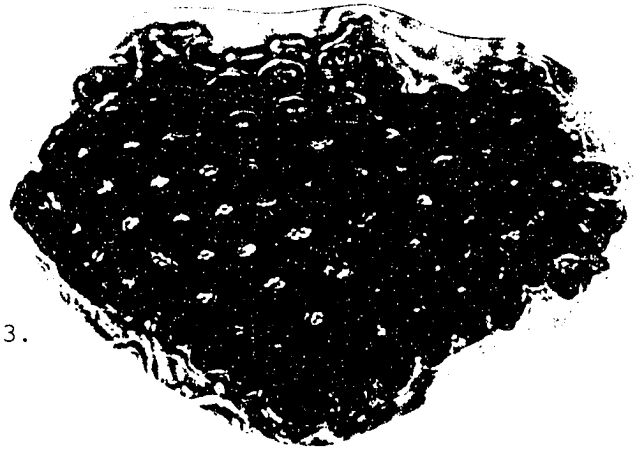
Slide No. 94SR (MZ) D006(2)

3. *Foveosporis* sp. cf. *F. linearis* Krutzschh 1959: D5-21, ↑, 14D

Plate 102

1.

2.



3.

25 µm

Plate 103

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(1)

1. *Vitrisporites pallidus* (Reissinger) Nilsson 1958: D4-19, ↓, 8D-E

Slide No. 94SR (MZ) D006 (+20)

2. *Sequoia papillapollenites* (Rouse) Srivastava 1969: R1-28, ↓, 18T

Slide No. 94SR (MZ) D006(1)

3. *Cycadopites* reticulatus (Nilsson) Cornet and Traverse 1975: D4-5, ↓, 32Q-R

4. *Vitrisporites* sp.: D3-24, ↓, 27-28R

Slide No. 94SR (MZ) D006(1)

5. *Podocarpidites granulatus* Singh 1971: D4-8, ↓, 30S

6. *P. granulatus*: D4-26, ↑, 5V

7. *Podocarpidites radiatus* Brenner 1963: D4-30, ↑, 8-9J

8. *Piceapollenites* sp.: D5-37, ↓, 35C

9. *Cedripites cretaceus* Pocock 1962: D4-25, ↑, 4W

Plate 103

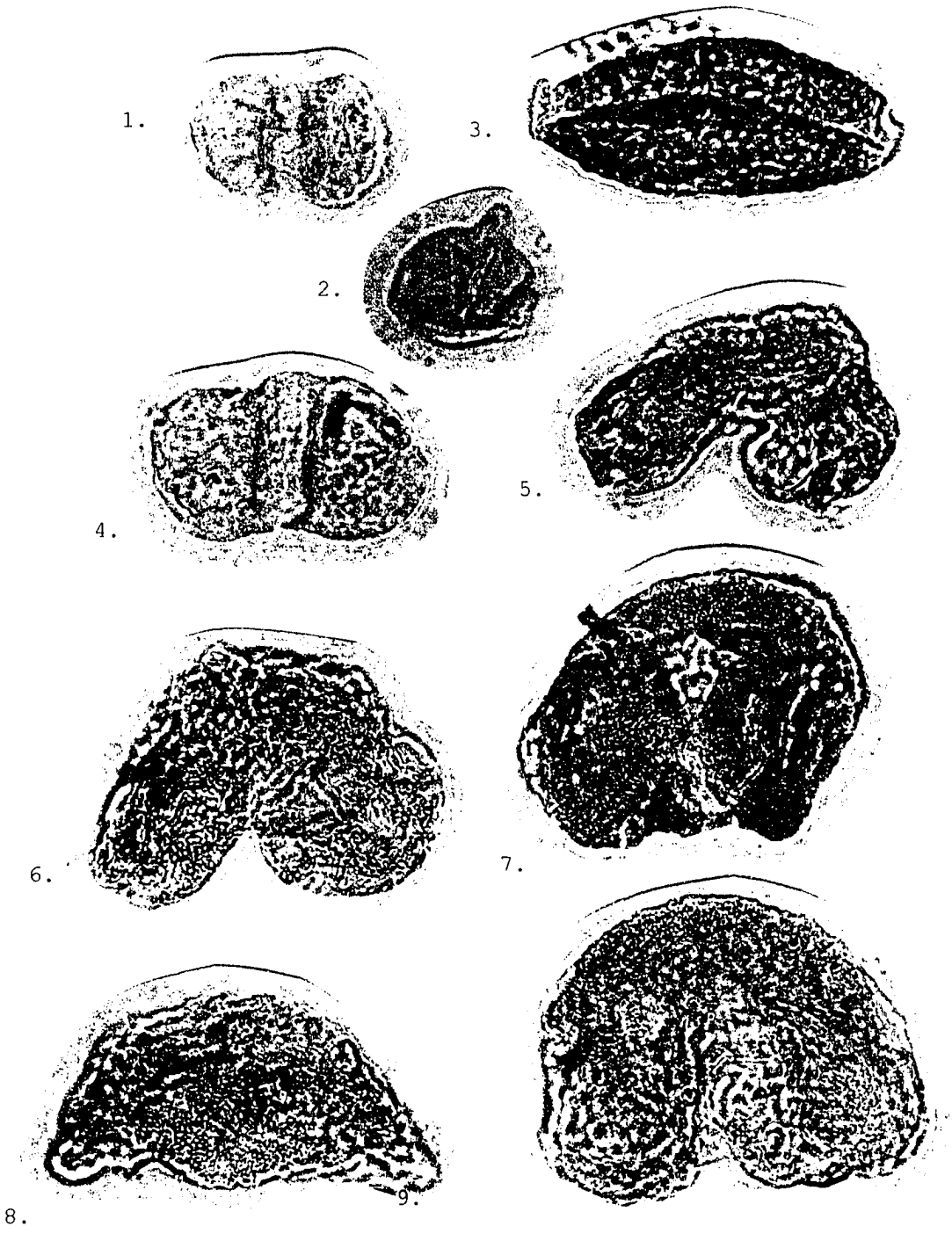


Plate 104

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(1)

1. *Abiespollenites* sp.: D4-32, ↑, 11-12C

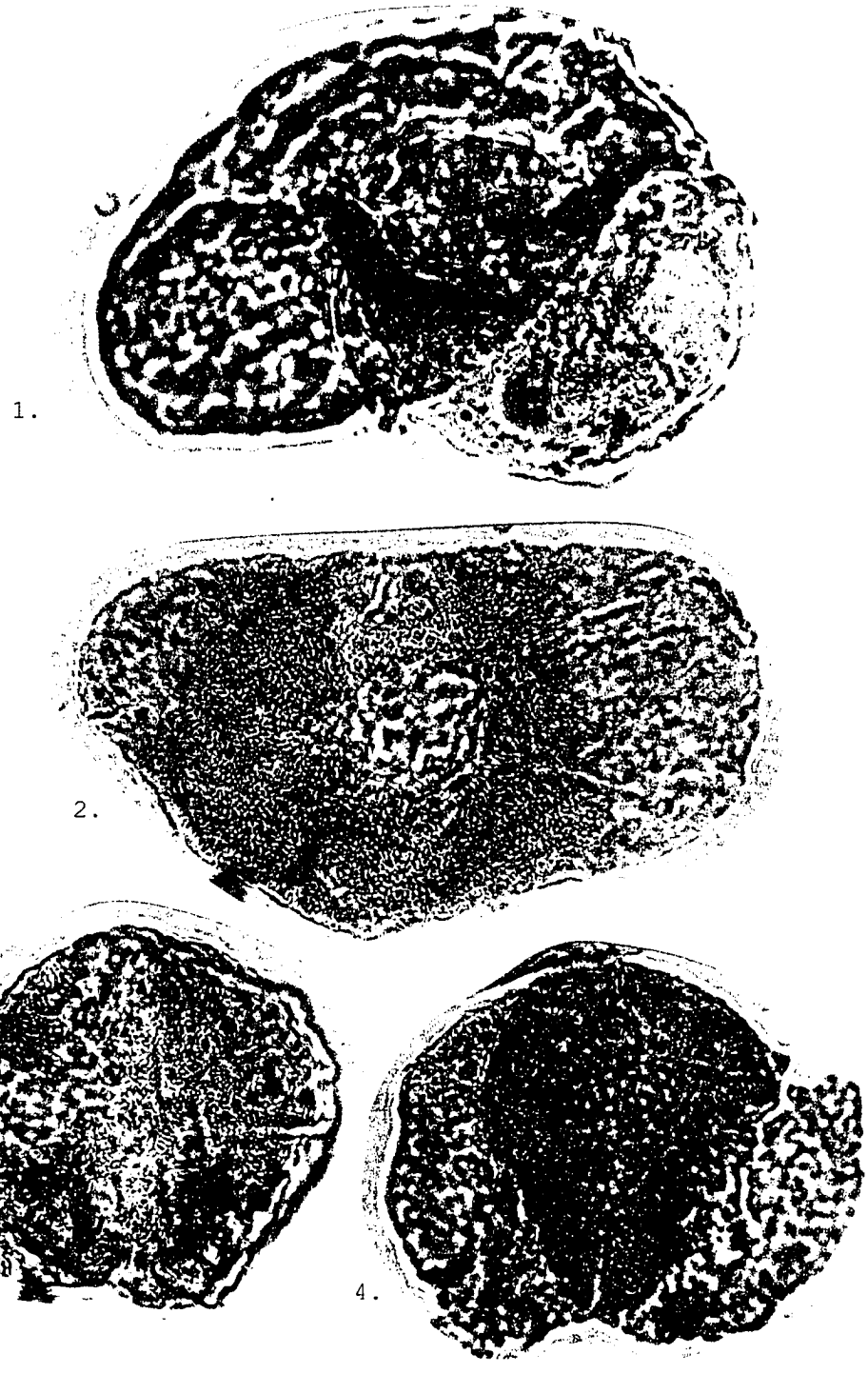
2. *Alisporites bilateralis* Rouse 1959: D4-22, ↑, 2L

3. *Cedripites canadensis* Pocock 1962: D4-21, ↑, 1Q

Slide No. 94SR (MZ) D006(1)

4. *C. canadensis*: D5-29, ↑, 20Q

Plate 104



25 μm

Plate 105

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(1)

1. *Platysaccus* sp.: D4-33, ↑, 11C

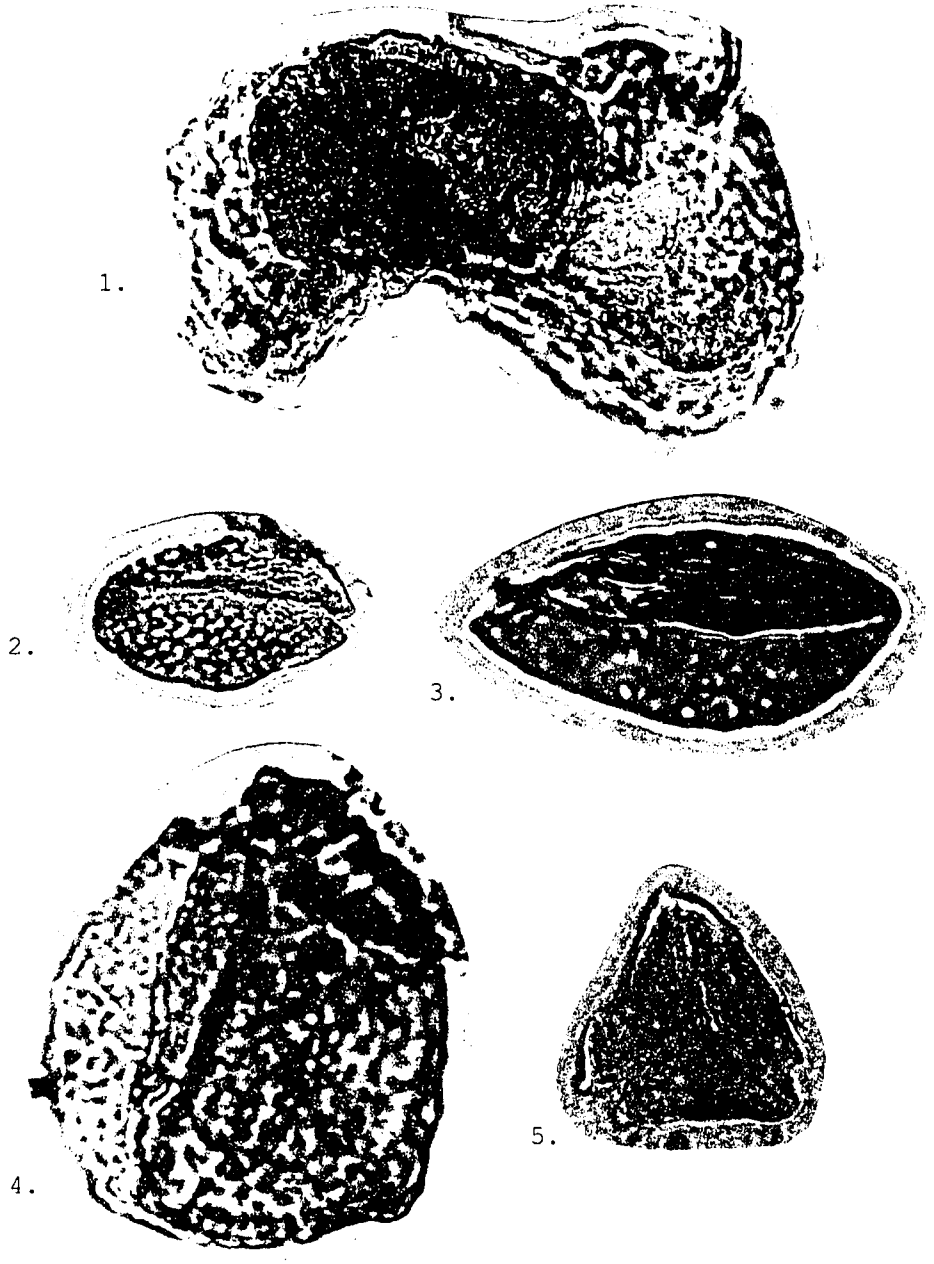
2. *Liliacidites inaequalis* Singh 1971: D4-4, ↓, 33-34M

3. *Fraxinoipollenites* sp.: D5-32, ↓, 36N

4. *Penetetrapites inconspicuus* Sweet 1986: D3-2, ↑, 17-18D

5. *Cupanieidites terrestris* Braman 2001: D5-30, ↓, 36T-U

Plate 105



25 µm

Plate 106

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(1)
1. *Momipites inaequalis* Anderson 1960: D4-12, ↓, 25E

Slide No. 94SR (MZ) D006(2)
2. *Proteacidites thalmanni* Anderson 1960: D5-7, ↑, 4N

Slide No. 94SR (MZ) D006(1)
3. Unknown genus: D4-37, ↑, 14M

4. cf. *Quercus explanata* Anderson 1960: D4-14, ↓, 23Q-R

5. *Fraxinoipollenites* sp.: D5-33, ↓, 36V

Slide No. 94SR (MZ) D006(2)
6. *Tricolpites micromunus* (Groot and Penny) Singh 1971: D5-19, ↑, 12U

Slide No. 94SR (MZ) D006(1)
7. *Nyssapollenites albertensis* Singh 1971: D4-3, ↓, 34M

Slide No. 94SR (MZ) D006(2)
8. *Nyssapollenites bindae* Srivastava 1969: D5-17, ↑, 11B-C

Slide No. 94SR (MZ) D006(1)
9. *Retitricolpites georgensis* Brenner 1963: D5-36, ↓, 35H

Plate 106

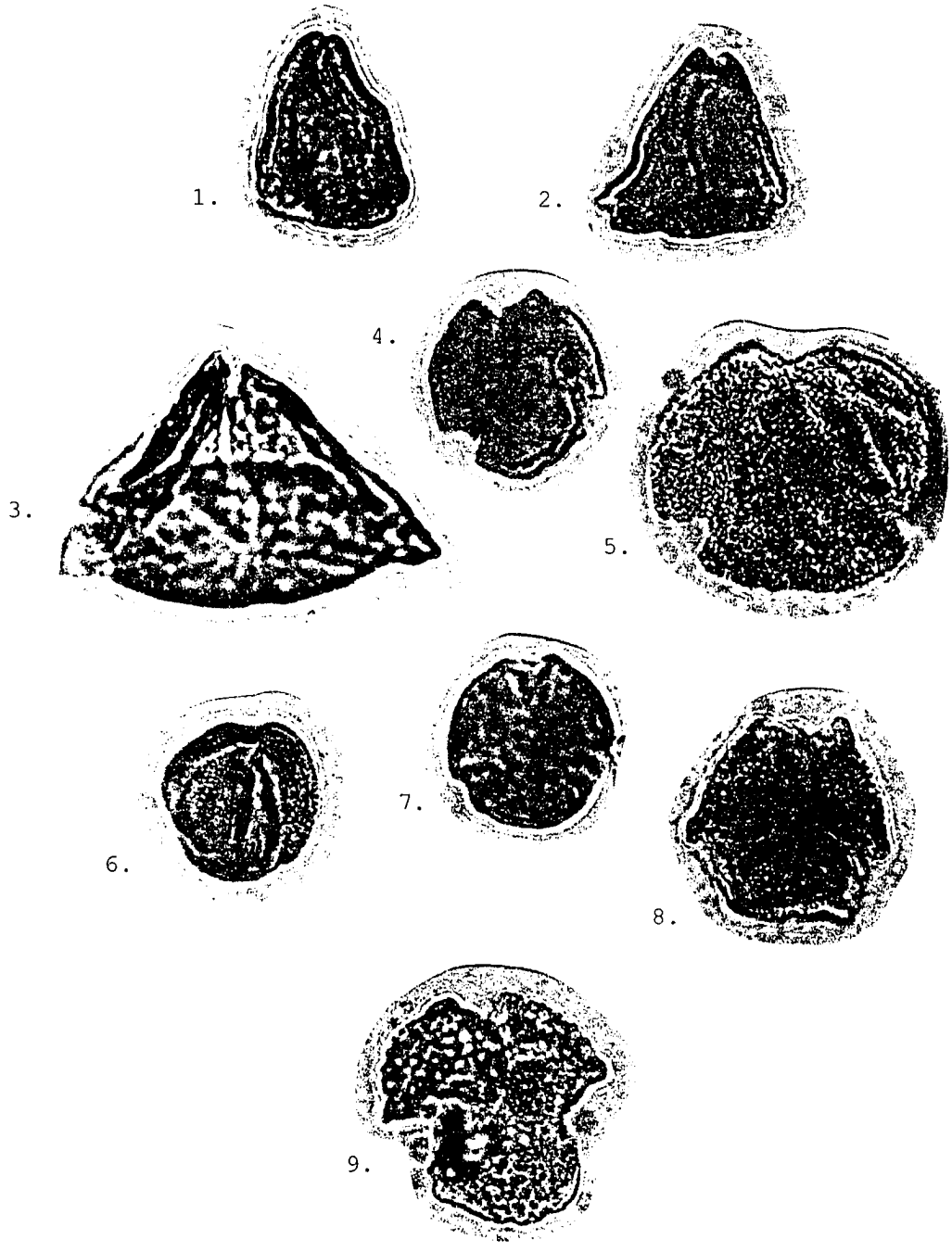


Plate 107

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006 (+20)

1. *Ilexpollenites obscuricostata* (Traverse) Srivastiva 1967: R1-36, ↑, 5E

2. *Fraxinoipollenites constrictus* (Pierce) Chlonova 1976: R1-16, ↓, 31W

3. *Proteacidites auratus* Srivastiva 1969: R1-34, ↑, 2K

4. *Accuratipollis evanidus* Chlonova 1961: R1-37, ↑, 17H

5. *Dryadopollis* sp. A Braman 2001: R1-19, ↓, 28W

6. *Extratriporopollenites* sp.: R6-23, ↓, 21X-Y

Plate 107

Plate 108

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(1)

1. *Cranwellia rumseyensis* Srivastava 1966: D5-35, ↓, 35P-Q

Slide No. 94SR (MZ) D006(2)

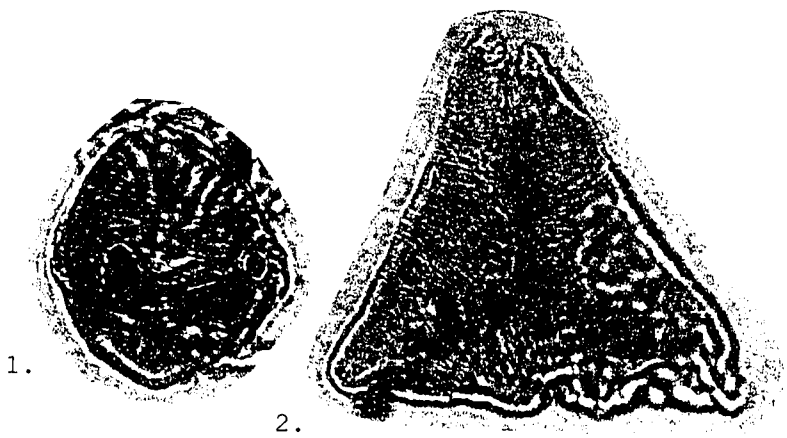
2. *Cranwellia striata* (Couper 1953) Srivastava 1966: D5-10, ↑, 6-7S

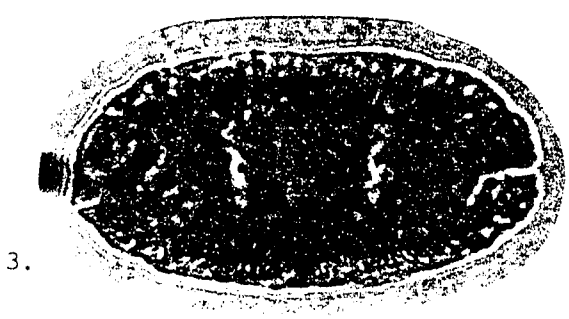
3. *Wodehouseia gracile* (Samoilovitch *in* Samoilovitch and Mchedlishvili) Samoilovitch 1966: D5-18, ↑, 11S

Slide No. 94SR (MZ) D006 (1)

4. *Scollardia trapaformis* Srivastava 1966: D5-22, ↑, 17-18K

Plate 108





25 μm

Plate 109

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(1)

1. *Mancicorpus* sp. cf. M. trapeziforme Mchedlishvili 1961: R1-30a, ↓, 19-20N

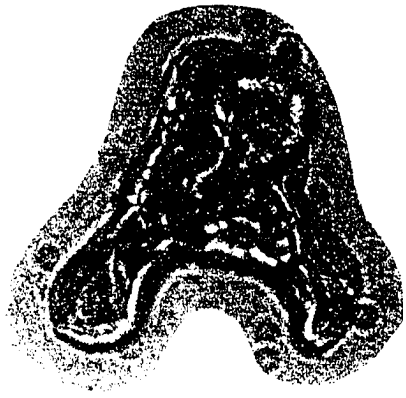
2. *Aquilapollenites bertillonites* Funkhouser 1961: R1-18, ↓, 28V

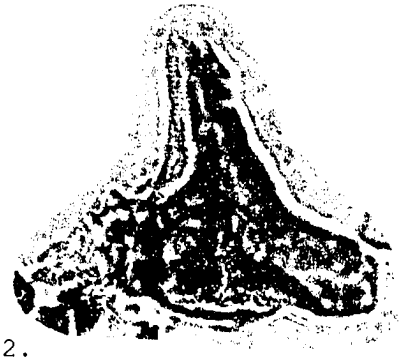
3. *Aquilapollenites spinulosus* Funkhouser 1961: R1-22a, ↓, 26Q

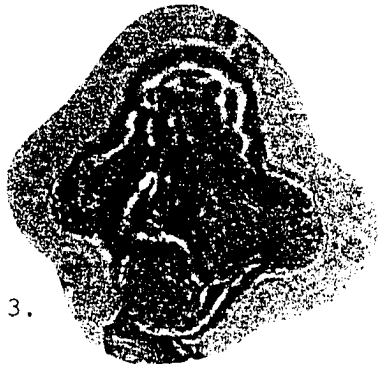
4. *Aquilapollenites conatus* Norton 1965: R1-24a, ↓, 24Q

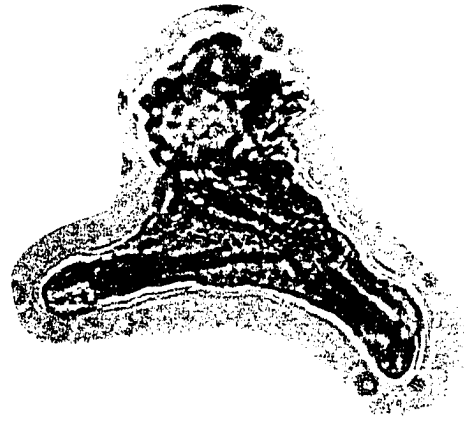
5. cf. *Mancicorpus canadiana* (Srivastava) Tschudy 1971: R1-16a, ↓, 28S-29T

Plate 109

1. 

2. 

3. 

4. 

5. 

25 μm

Plate 110

Mazuma Creek Palynoflora
Florule D-6

Slide No. 94SR (MZ) D006(2)

1. *Aquilapollenites senonicus* (Mchedlishvili) Tschudy and Leopold 1969: D5-11, ↑, 7F

Slide No. 94SR (MZ) D006(1)

2. *A. senonicus*: D4-24, ↑, 4-5H

3. *Aquilapollenites scabridus* Tschudy 1969: D4-15, ↓, 22V-W

Slide No. 94SR (MZ) D006(2)

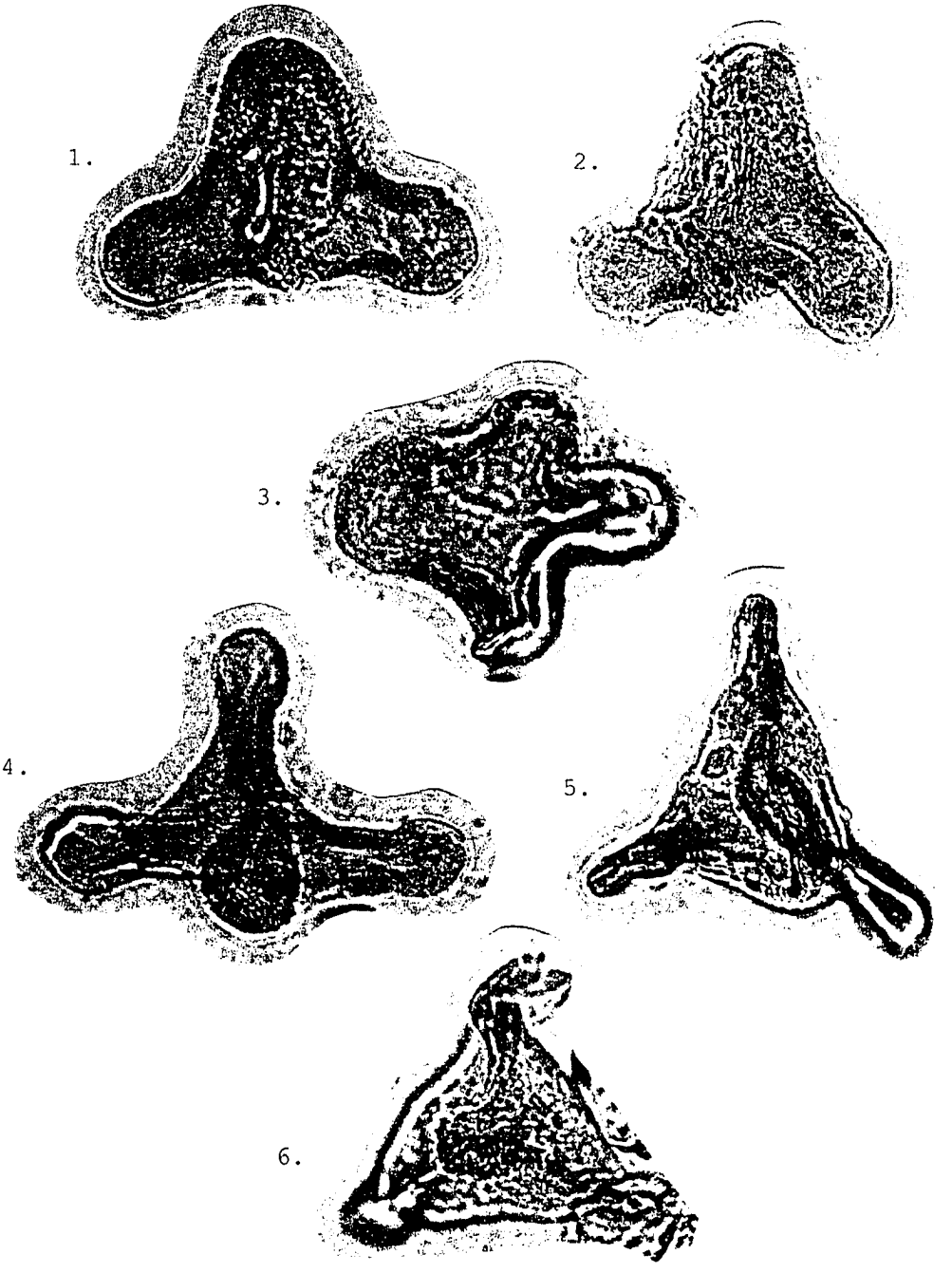
4. *Aquilapollenites delicatus* Stanley var. *delicatus* Tschudy and Leopold 1971: D5-16, ↑, 9-10 S

Slide No. 94SR (MZ) D006(1)

5. *Aquilapollenites trialatus* Rouse 1957: D4-29, ↑, 8P

6. *Aquilapollenites contiguus* Tschudy 1969: D4-9, ↓, 26H

Plate 110



25 µm

Plate 111

Mazuma Creek Palynoflora
Florule D-12

Slide No. 94SR (MZ) D0012(1)
1. *Polypodiidites* sp.: D6-19, ↓, 27R

Slide No. 94SR (MZ) D0012(2)
2. *Hazaria canadiana* Srivastava 1971: D6-6, ↑, 5M

Slide No. 94SR (MZ) D0012(1)
3. *Foveosporites* sp.: D6-21, ↓, 24-25H

4. *Microreticulatisporites diatretus* Norris 1969: D6-33, ↑, 6L

5. *Gleicheniidites umbonatus* (Bolkhovitina) Bolkhovitina 1968: D6-26, ↓, 23M

Slide No. 94SR (MZ) D0012(2)
6. Converrucosisporites sp. cf. C. cameronii (de Jersey) Playford and Dettmann 1965: D6-8, ↑, 10L

Slide No. 94SR (MZ) D0012(1)
7. *Gleicheniidites* sp.: D6-24, ↓, 24V

Slide No. 94SR (MZ) D0012(2)
8. *Gleicheniidites* sp.: D6-7, ↑, 8-9J

Slide No. 94SR (MZ) D0012(1)
9. *Dictyophyllidites mortonii* (de Jersey) Playford and Dettmann 1965: D6-36, ↑, 10W

Plate 111

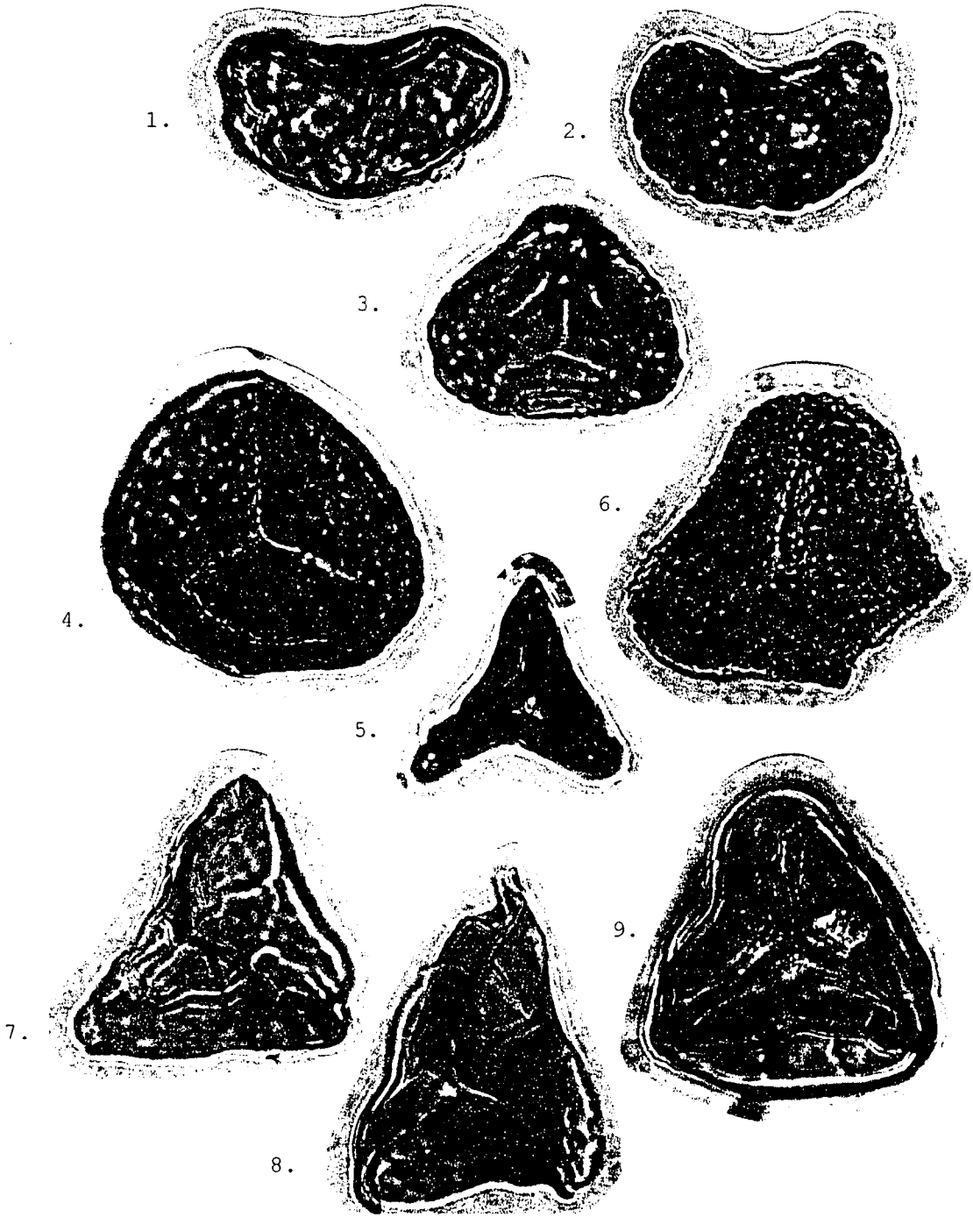


Plate 112

Mazuma Creek Palynoflora
Florule D-12

Slide No. 94SR (MZ) D0012(1)

1. *Cyathidites australis* Couper 1953: D6-34, ↑, 7U-V

2. *Cicatricosisporites* sp.: D6-30, ↑, 1L

3. *Interulobites* sp. cf. *I. intraverrucatus* Brenner 1963: D6-35, ↑, 9G

4. *Polycingulatisporites reduncus* (Bolkhovitina) Playford and Dettmann 1965: D6-31, ↑, 4N

Plate 112

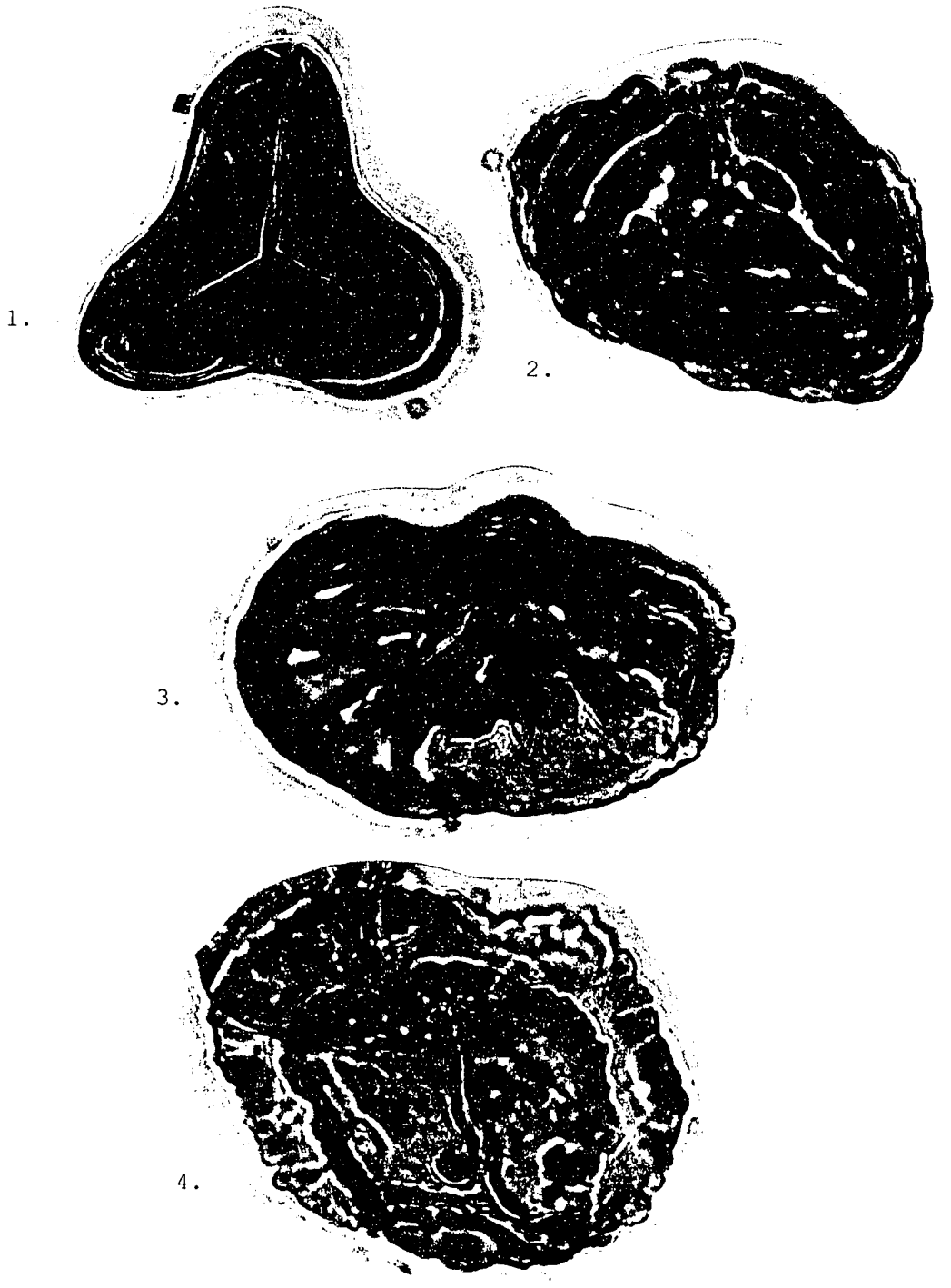


Plate 113

Mazuma Creek Palynoflora
Florule D-12

Slide No. 94SR (MZ) D0012(1)

1. *Ephedrapites* sp.: D5-3, ↑, 13H

2. *Phyllocladites* sp. cf. *P. microreticulatus* Brenner 1963: D6-15, ↓, 37-38R

3. *Cedripites canadensis* Pocock 1962: D6-18, ↓, 28L-M

4. *Parvisaccites* sp. cf. *P. rugulatus* Brenner 1963: D5-2, ↑, 13Q

5. *Platysaccus* sp.: D6-37, ↑, 12W

Plate 113

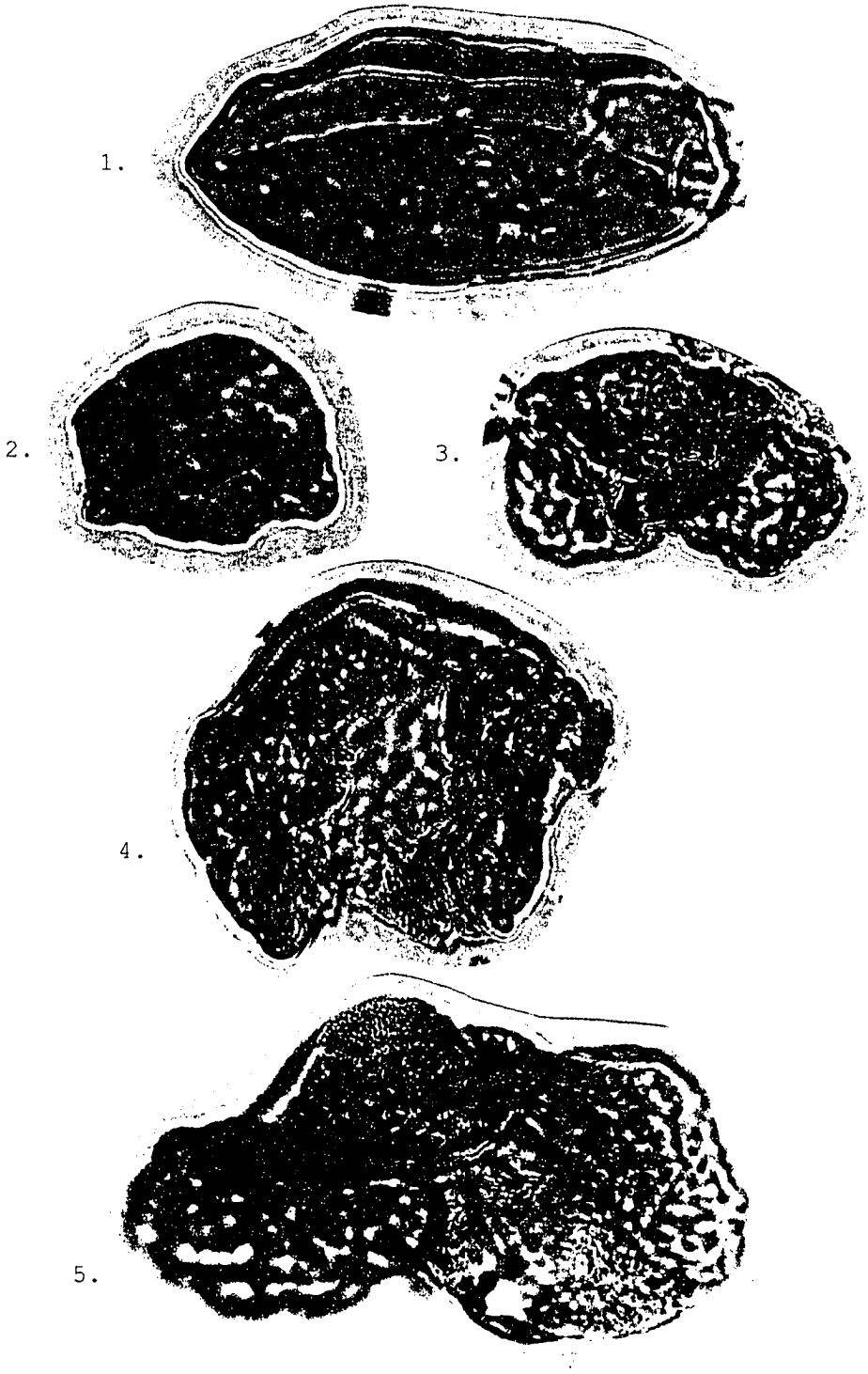


Plate 114

Mazuma Creek Palynoflora
Florule D-12

Slide No. 94SR (MZ) D0012(1)

1. Unknown genus: D6-20, ↓, 27W-X

2. *Extraporopollenites* sp.: D6-17, ↓, 28S

Slide No. 94SR (MZ) D0012(2)

3. *Tricolpites microreticulatus* Belsky, Boltenhagen and Potonié 1965: D6-9, ↑, 12R-S

4. *Retitricolpites georgensis* Brenner 1963: D6-5, ↑, 3K-L

Slide No. 94SR (MZ) D0012(1)

5. *Cranwellia rumseyensis* Srivastava 1966: D6-14, ↓, 30V

Slide No. 94SR (MZ) D0012(2)

6. *Proteacidites auratus* Srivastava 1969: D6-10, ↑, 12W

Slide No. 94SR (MZ) D0012(1)

7. *Proteacidites thalmanni* Anderson 1960: D6-27, ↓, 22N

8. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: D6-25, ↓, 24W

Slide No. 94SR (MZ) D0012(2)

9. *Aquilapollenites senonicus* (Mtchedlishvili) Tschudy and Leopold 1969: D6-11, ↑, 14-15D

Plate 114

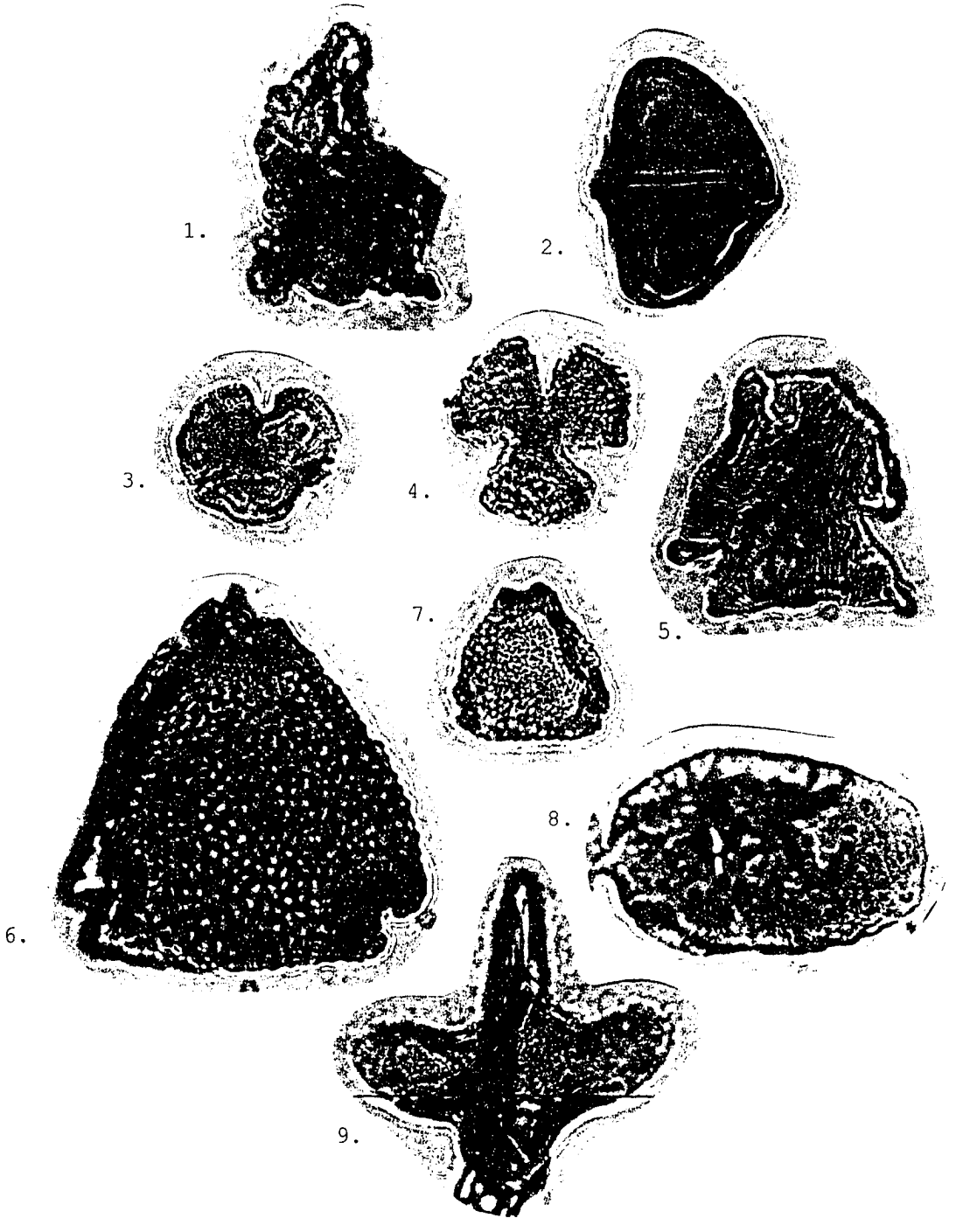


Plate 115

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(1)

1. *Neoraistrickia truncata* (Cookson) Potonié 1956: D8-25, ↓, 28F

Slide No. 94SR (MZ) D0013(2)

2. *Stereisporites antiquasporites* (Wilson and Webster) Dettmann 1963: D9-31, ↑, 5J

3. *Cyathidites australis* Couper 1963: D8-1, ↑, 6H

Slide No. 94SR (MZ) D0013(1)

4. *Laevigatosporites* sp.: D8-20, ↓, 30-31P

5. *Reticuloidosporites pseudomurii* Elsik 1968: D8-23, ↓, 28H

6. *Lycopodiumsporites* sp.: D8-34, ↓, 24-25N

7. *Lycopodiumsporites crassimacerius* Hedlund 1966: D7-34, ↑, 19G-H

8. *Baculatisporites* sp.: D8-36, ↓, 25S-T

9. *Deltoidospora neddeni* (Polonié) Orbell 1973: D7-36, ↑, 20M-N

Plate 115

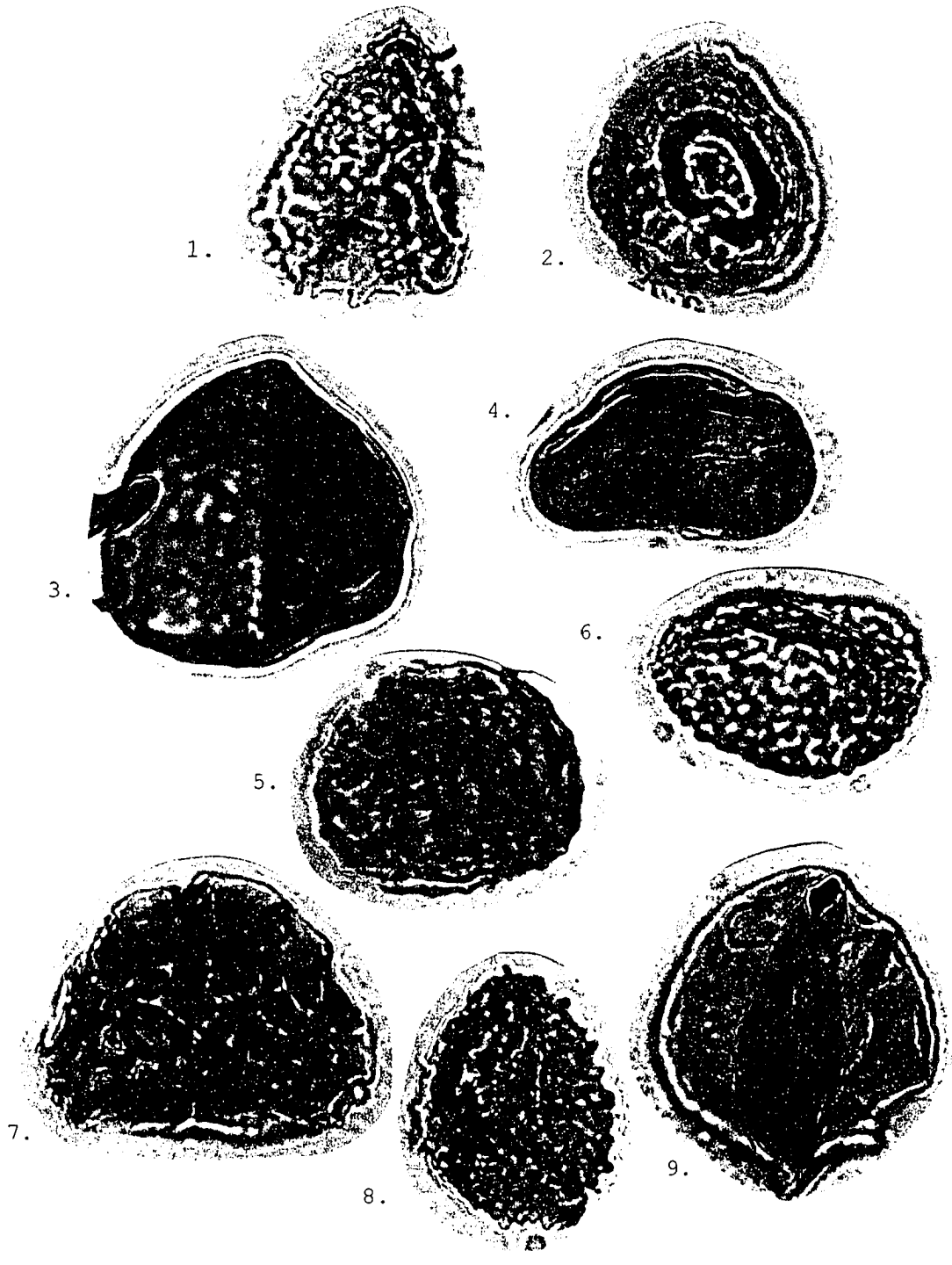


Plate 116

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(1)

1. *Biretisporites* sp. cf. *B. potoniaei* Delcourt and Sprumont 1955: D7-26, ↑, 14X

2. *Dictyophyllidites mortonii* (de Jersey) Playford and Dettmann 1965: D7-7, ↑, 3U

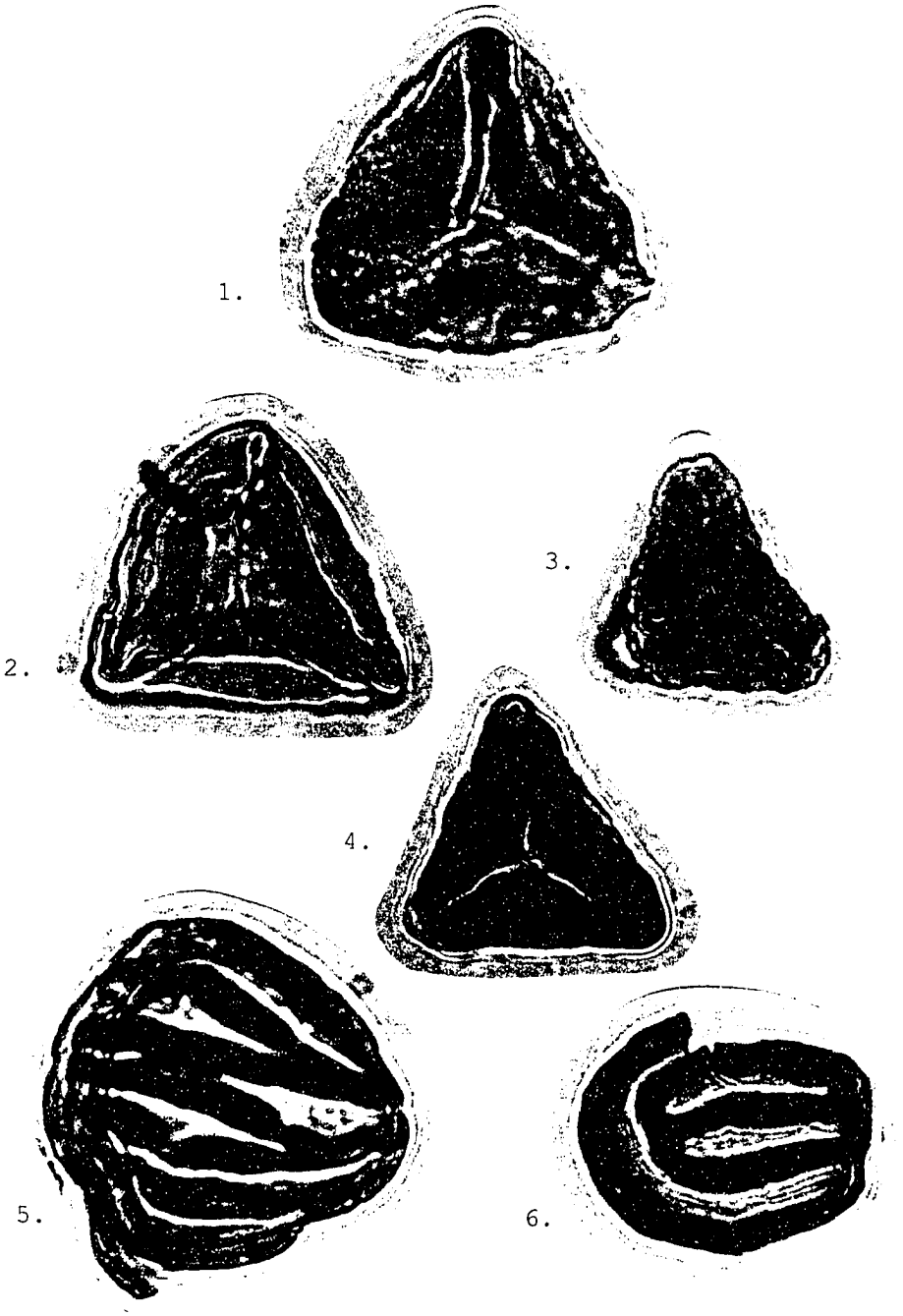
3. *Deltoidospora juncta* (Kara-Murza) Singh 1964: D7-4, ↓, 21S

4. *Undulatisporites fossulatus* Singh 1971: D8-29, ↓, 26V

5. *Cicatricosisporites* sp.: D7-25, ↑, 13-14V

6. *Cicatricosisporites hughesi* Dettmann 1963: D7-3, ↓, 22M-N

Plate 116



25 μm

Plate 117

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(1)

1. *Cicatricosisporites* sp.: D7-9, ↑, 4L-M

2. *Cicatricosisporites radiatus* Krutzsch 1959: D8-24, ↓, 28G

3. *Cicatricosisporites* sp.: D7-23, ↑, 13T

Slide No. 94SR (MZ) D0013(2)

4. *Cicatricosisporites* sp.: D9-35, ↑, 6Q

Slide No. 94SR (MZ) D0013(1)

5. *Cicatricosisporites* sp.: D7-27, ↑, 14N

6. *Cicatricosisporites* sp. cf. *C. imbricatus* (Markova) Singh 1971: D7-24, ↑, 13U

Plate 117

Plate 118

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(2)

1. *Polycingulatisporites reduncus* (Bolkhovitina) Playford and Dettmann 1965: D8-7, ↑, 14Y

2. *Leptolepidites verrucatus* Couper 1953: D8-2, ↑, 7L

Slide No. 94SR (MZ) D0013(1)

3. *Camarozonosporites insignis* Norris 1967, proximal view: D7-29, ↑, 15J

4. *C. insignis,* distal view: D7-31, ↑, 17-18P

Plate 118

Plate 119

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(1)

1. cf. *Taurocusporites segmentatus* Stover 1962: D7-33, ↑, 19-20M

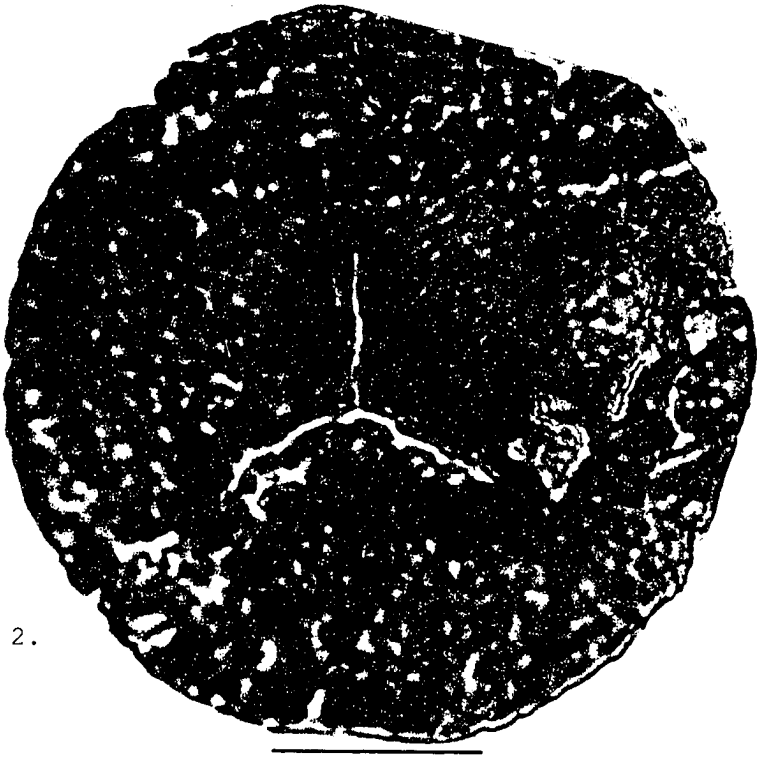
Slide No. 94SR (MZ) D0013(2)

2. Unknown genus: D8-8, ↑, 15K

Plate 119

1.

2.



25 µm

Plate 120

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(1)

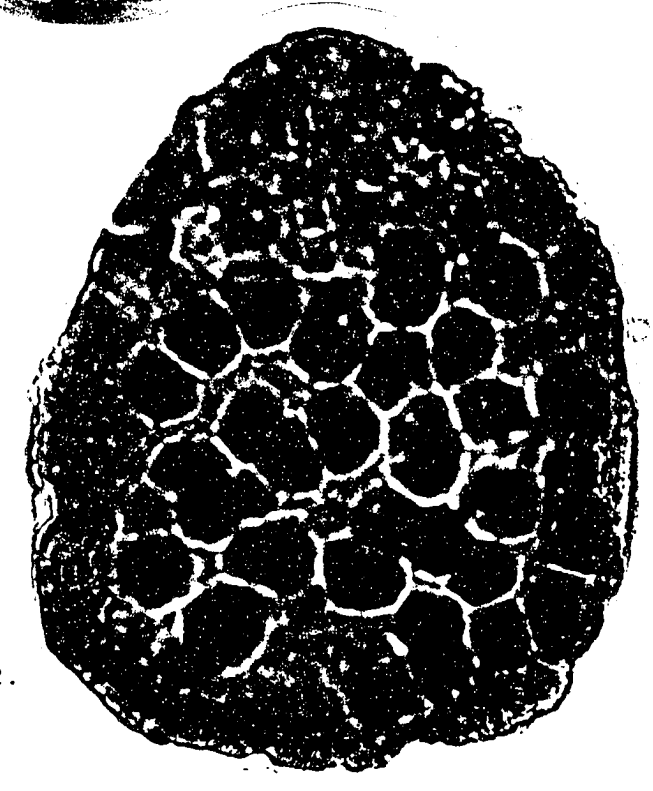
1. *Taurocusporites segmentatus* Stover 1962, proximal view: D7-22, ↑, 13T

2. *T. segmentatus,* distal view: D7-32, ↑, 17-18M

Plate 120

1.

2.



25 µm

Plate 121

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(1)

1. *Podocarpidites* sp. cf. *P. ellipticus* Cookson 1947: D7-15, ↑, 8L

2. *Abiespollenites* sp.: D7-8, ↑, 3-4K

3. *A.* sp.: D7-9, ↑, 4L-M

Slide No. 94SR (MZ) D0013(2)

4. *Parvisaccites* sp. cf. *P. radiatus* Couper 1958: D8-4, ↑, 9N

5. *Pinuspollenites* sp.: D8-9, ↑, 19P

Slide No. 94SR (MZ) D0013(1)

6. *Podocarpidites multesimus* (Bolkhovitina) Pocock 1962: D8-21, ↓, 30U

Plate 121

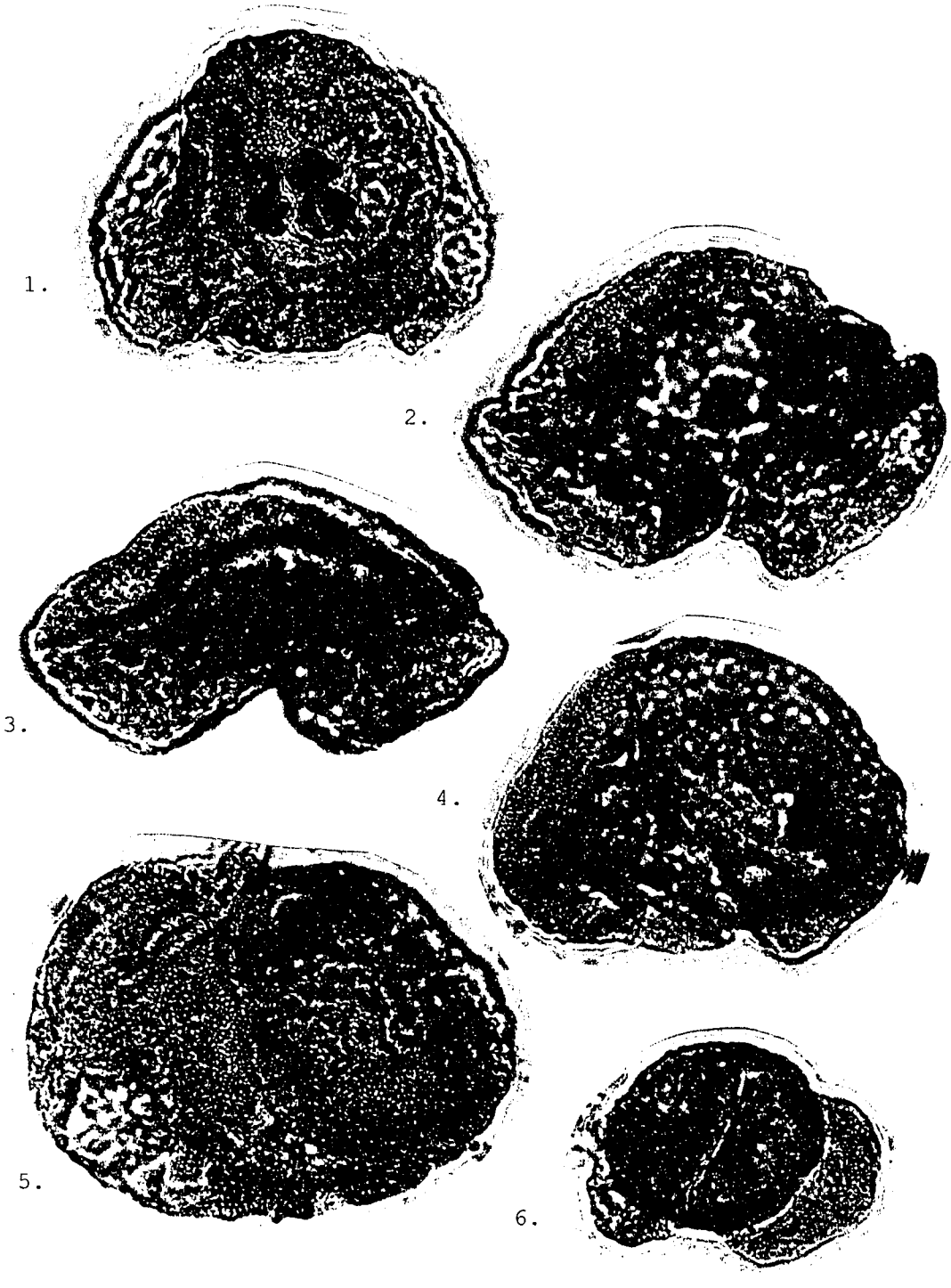


Plate 122

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(2)

1. *Foveosporis* sp. cf. *F. linearis* Krutzsch 1959: A1-36, ↑, 6F

Slide No. 94SR (MZ) D0013(1)

2. *Spermatites* sp.: D7-28, ↑, 14-15L

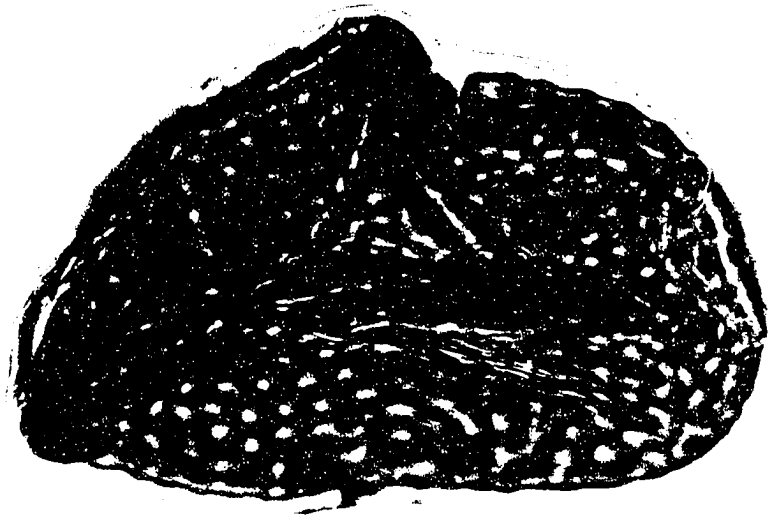
3. *Bombacacipites* sp. cf. *B. nacimientoensis* Anderson 1960: D8-15, ↓, 33L

Slide No. 94SR (MZ) D0013(2)

4. *Penetetrapites inconspicuus* Sweet 1986: A1-34, ↑, 6J

Plate 122

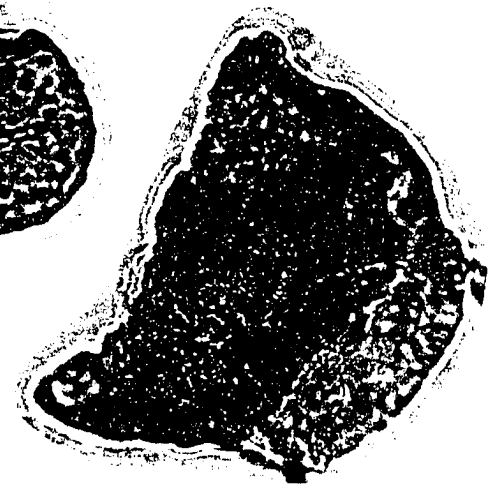
1.



2.

3.

4.



25 µm

Plate 123

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(2)

1. *Ulmoideipites herbridicus* (Simpson) Sweet 1986: R9-30, ↑, 4-5J

Slide No. 94SR (MZ) D0013(1)

2. *Tricolpites micromunus* (Groot and Penny) Singh 1971: D8-14, ↓, 37T

3. *Retitricolpites georgensis* Brenner 1963: D7-1, ↓, 24V-W

4. *Nyssapollenites albertensis* Brenner 1963: D8-19, ↓, 30K

5. *Alnipollenites* sp.: D8-27, ↓, 27V

Slide No. 94SR (MZ) D0013(2)

6. *Betulapollenites* sp.: A1-33, ↑, 5L

Slide No. 94SR (MZ) D0013(1)

7. *Cranwellia striata* (Couper) Srivastava 1966: D8- 11, ↓, 39V

8. *Extratriporopollenites* sp.: D7-2, ↓, 23V

9. *Proteadicites retusus* Anderson 1960: D8-31, ↓, 26G-H

Plate 123

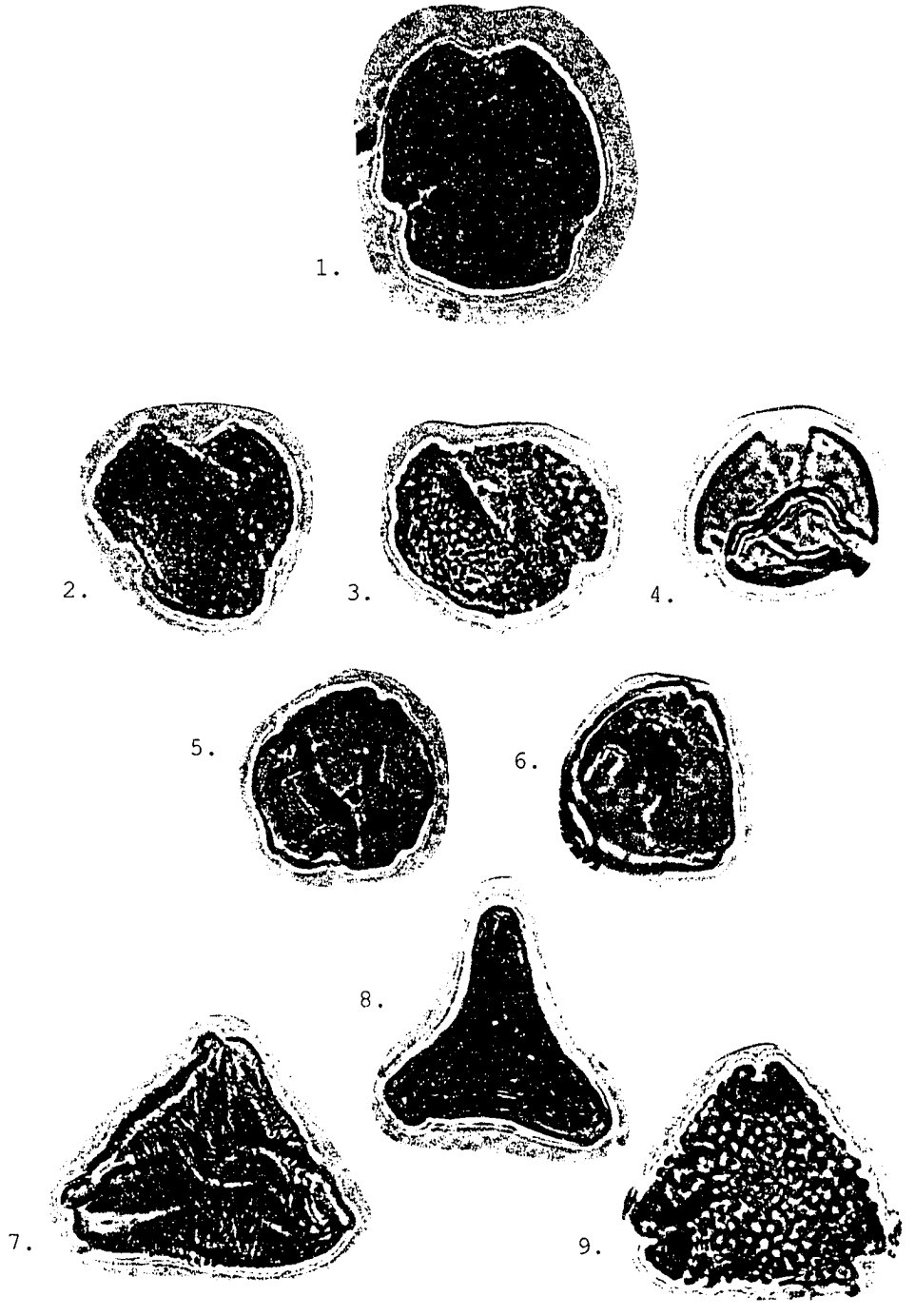


Plate 124

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(1)

1. *Spermatites* sp.: D7-35, ↑, 20D

2. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: D8-13, ↓, 36M

3. *Scollardia trapaformis* Srivastava 1966: D8-18, ↓, 32T

4. *Aquilapollenites spinulosus* Funkhouser 1961: D7-14, ↑, 7-8B

Slide No. 94SR (MZ) D0013(2)

5. *Aquilapollenites notabile* (Mtchedlishvili) Farabee 1990: D8-3, ↑, 7-8X

Plate 124

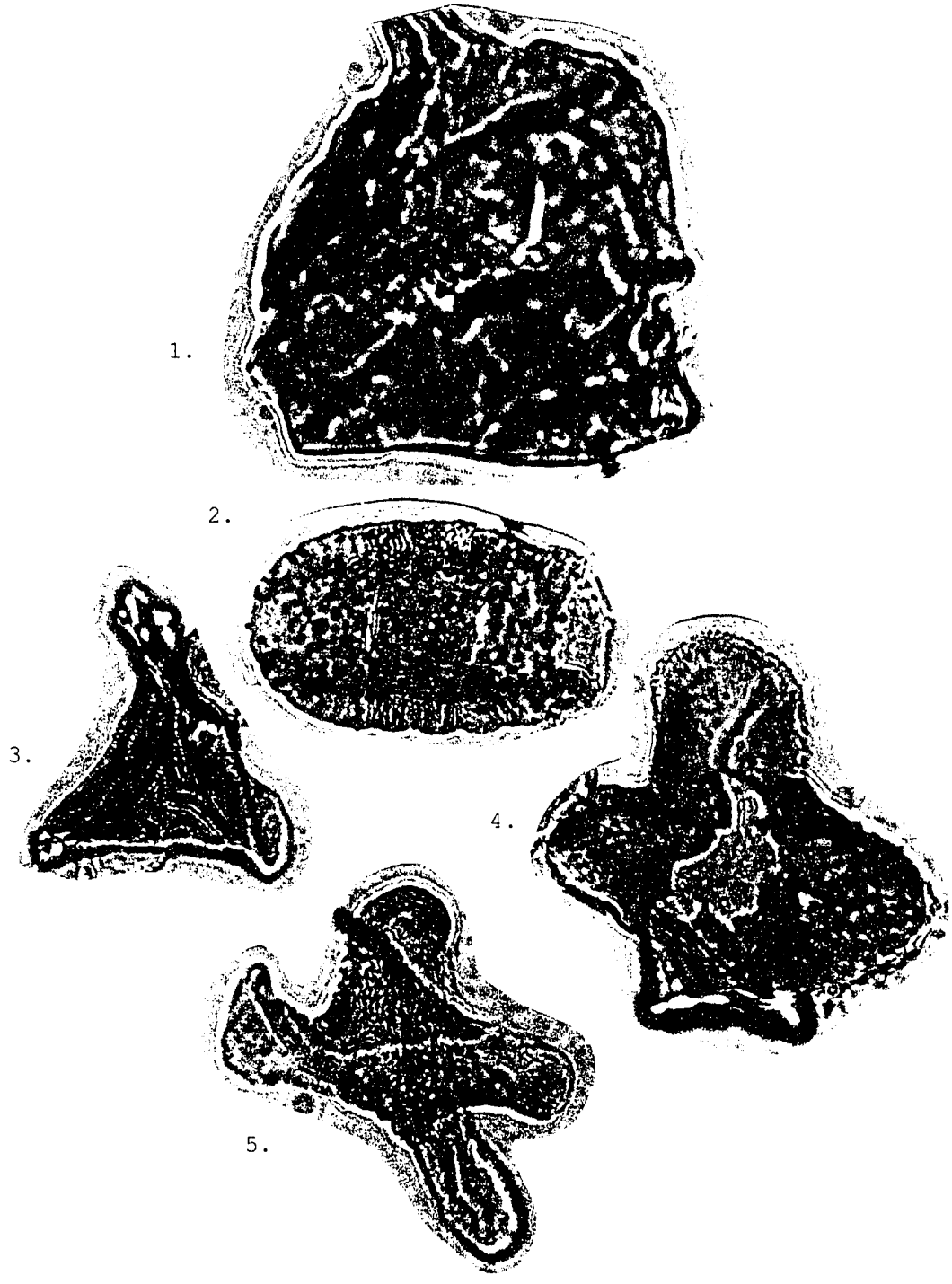


Plate 125

Mazuma Creek Palynoflora
Florule D-13

Slide No. 94SR (MZ) D0013(1)

1. *Aquilapollenites senonicus* (Mchedlishvili) Tschudy and Leopold 1969: D7-20, ↑, 12G

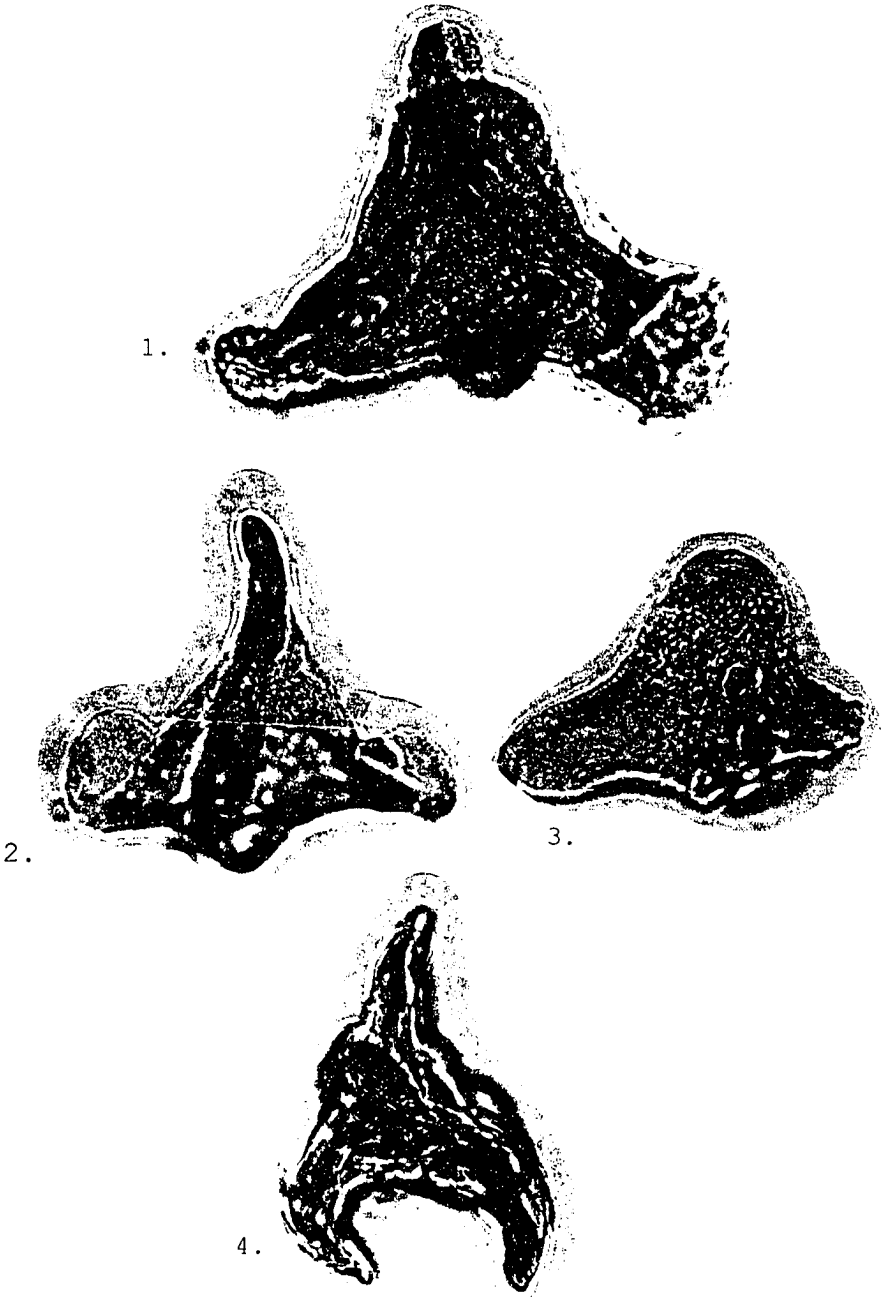
2. *A. senonicus*: D7-11, D7-12, ↑, 5S

Slide No. 94SR (MZ) D0013(2)

3. *A. senonicus*: A1-32, ↑, 5J

4. *Mancicorpus* sp.: D8-5, ↑, 12L

Plate 125



25 µm

APPENDIX E

Plate 126

Mazuma Creek Palynoflora
Florule E-3

Slide No. 94SR (MZ) E003

1. *Laevigatosporites* sp.: R15-17, ↑, 10-11E

2. *Baculatisporites comaumensis* (Cookson) Potonié 1956: R15-1, ↑, 1K

3. *Echinatisporis* sp.: R16-37, ↑, 1R

4. *Ceratosporites equalis* Cookson and Dettmann 1958: R16-32, ↓, 18U

5. *Retitriletes subreticulaesporites* (Rouse) Krutzsch 1963: R16-13, ↑, 8J

6. *Krauselisporites hastilobatus* Playford 1971: R15-5, ↑, 3-4V

7. *Deltoidospora juncta* (Kara-Murza) Singh 1964: R15-20, ↑, 11E

8. *Undulatisporites fossulatus* Singh 1971: R15-4, ↑, 4X

9. *Dictyophyllidites* sp.: R16-28, ↓, 23R

10. *Toroisporis delicatus* Doring, 1965 : R15-24, ↑, 13V

Plate 126

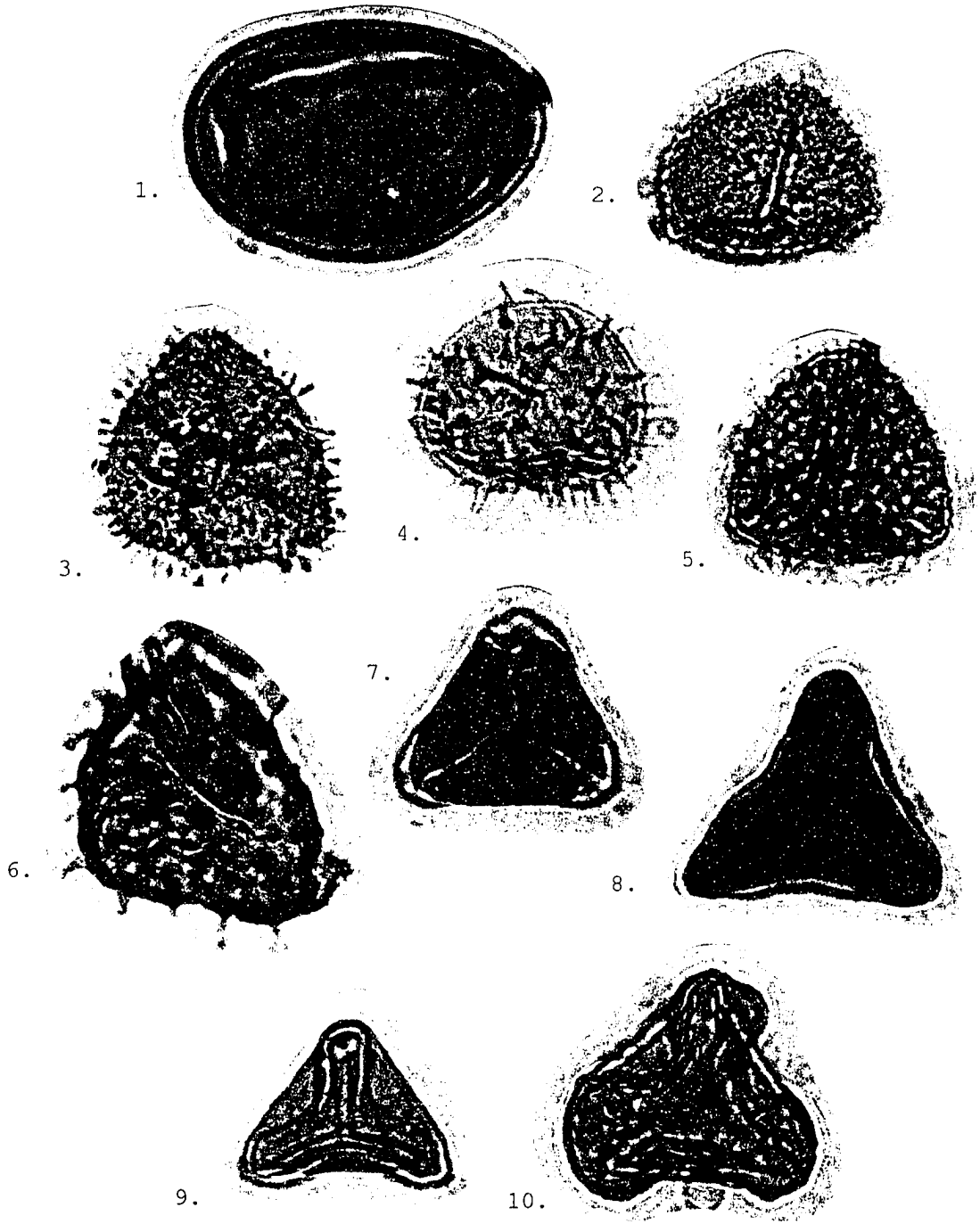


Plate 127

Mazuma Creek Palynoflora
Florule E-3

Slide No. 94SR (MZ) E003

1. *Gleicheniidites delicatus* (Bolkhovitina) Pocock 1970: R15-8, ↑, 5H

2. *Foveogleicheniidites confossus* (Hedlund) Burger in Norvick and Burger 1976: R15-12, ↑, 7K

3. *Gleicheniidites senonicus* Ross ex Delcourt and Sprumont 1955: R16-21, ↑, 14C

4. *Converrucosisporites* sp. cf. C. cameronii (de Jersey) Playford and Dettmann 1965: R16-22, ↓, 31N

5. *Retitriletes subreticulaesporites* (Rouse) Krutzsch 1963: R16-25, ↓, 26S

6. *Leptolepidites crepitus* Singh 1971: R16-30, ↓, 22M

7. *Gleicheniidites umbonatus* (Bolkhovitina) Bolhovitina 1968: R15-26, ↑, 14S

8. *Reticulisporites semireticulatus* (Burger) Norris 1967: R16-24, ↓, 26-27S

9. *Distaltriangulatisporites perplexus* (Singh) Singh 1971: R15-11, ↑, 6G

Plate 127

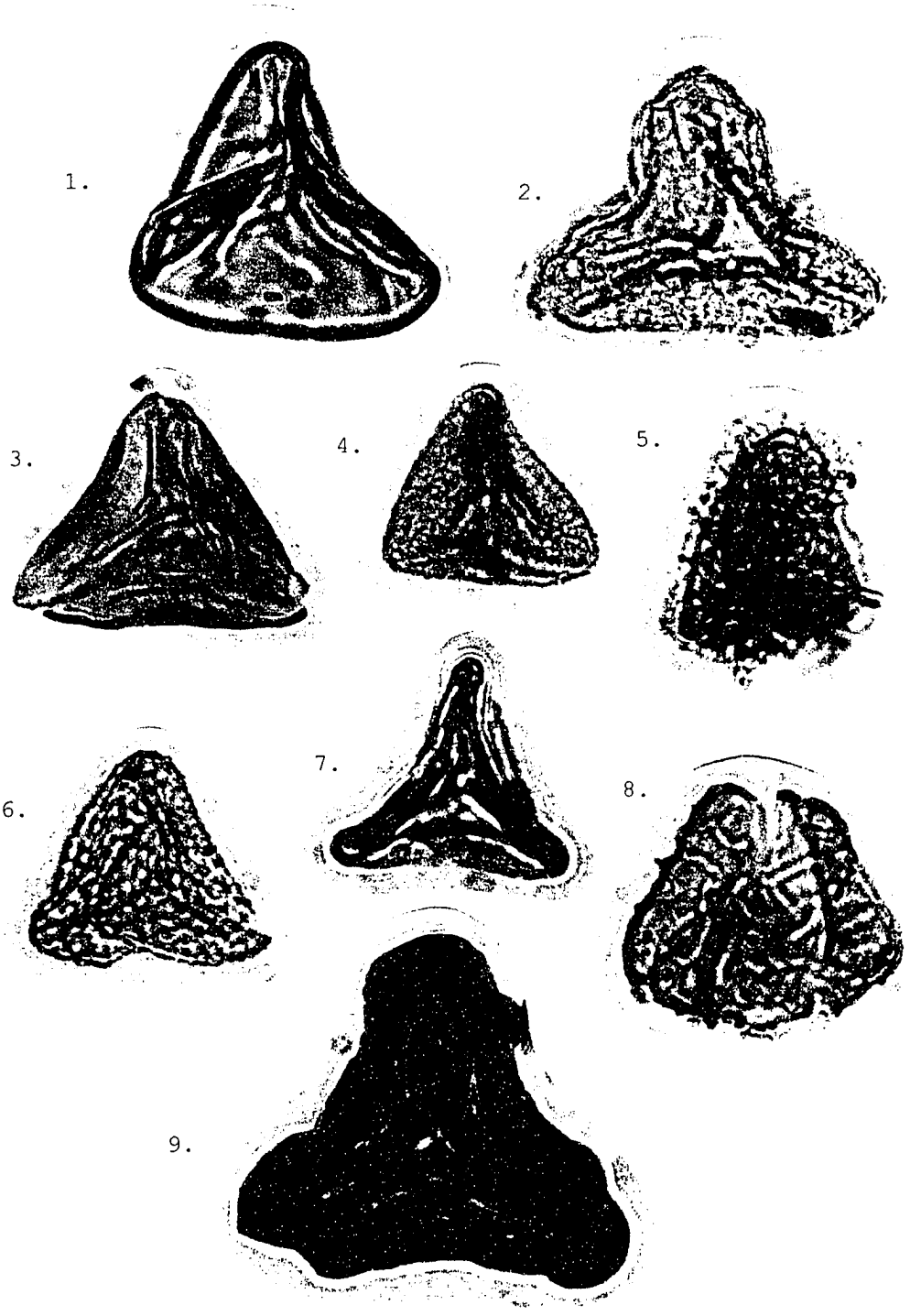


Plate 128

Mazuma Creek Palynoflora
Florule E-3

Slide No. 94SR (MZ) E003

1. *Psilatriletes radiatus* (Brenner) Doring 1966: R16-35, ↑, 1U

2. *Taurocuporites segmentatus* Stover 1962: R16-31, ↓, 22P

3. *Cicatricosisporites* sp.: R15-10, ↑, 10-11T

4. *Deltoidospora neddeni* (Potonié) Orbell 1973: R15-15, ↑, 9T

5. *Appendicisporites bilateralis* Singh 1971: R15-9, ↑, 5G

Plate 128

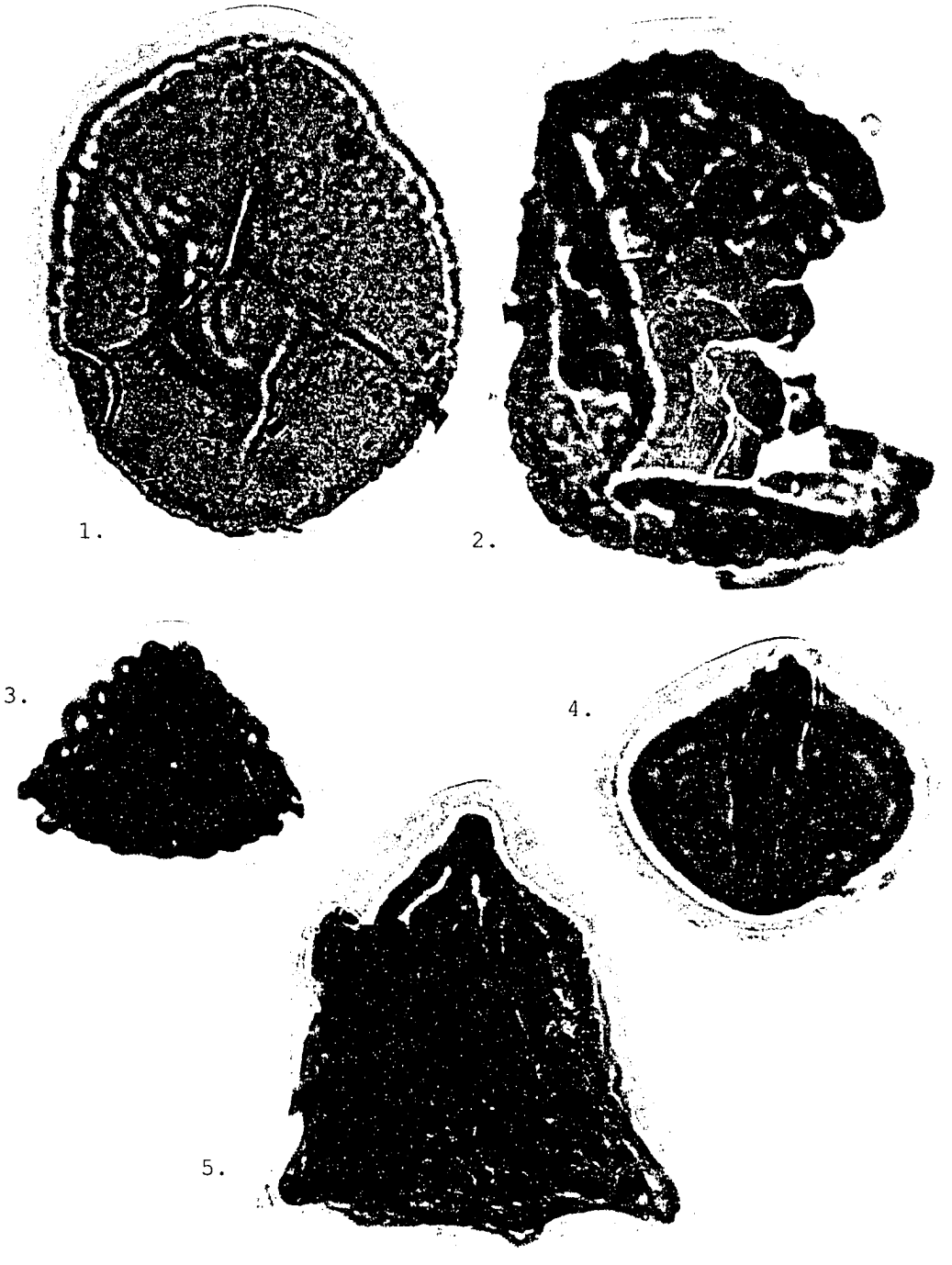


Plate 129

Mazuma Creek Palynoflora
Florule E-3

Slide No. 94SR (MZ) E003

1. *Taxodiaceapollenites hiatus* (Potonié) Kremp 1949: R15-23, ↑, 13K

2. *Pinuspollenites* sp.: R15-28, ↑, 14J

3. *Pinuspollenites* sp.: R15-2, ↑, 2F

4. *Cedripites* sp.: R15-19, ↑, 11H

5. *Piceapollenites* sp.: R15-21, ↑, 12F

Plate 129

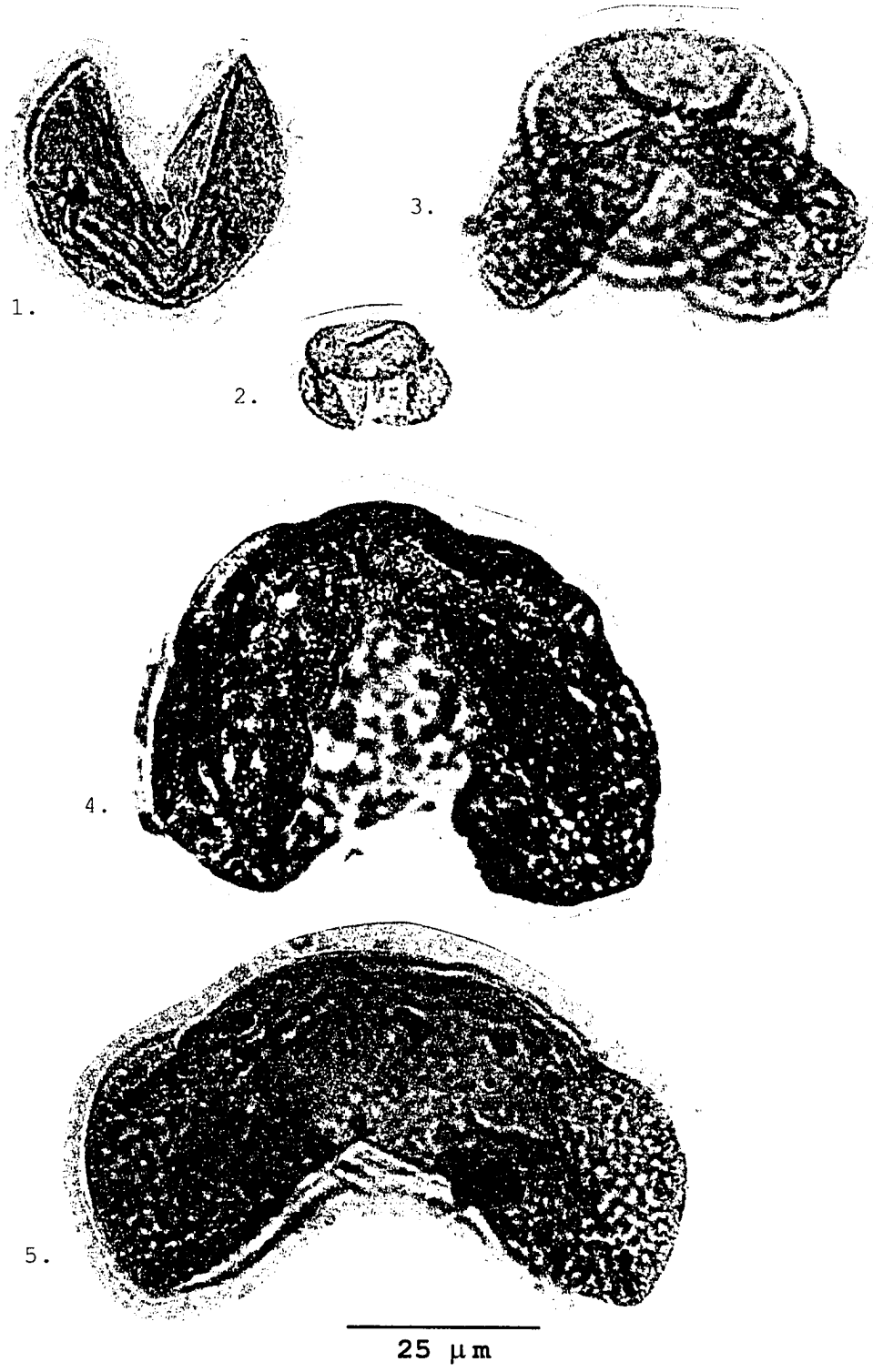


Plate 130

Mazuma Creek Palynoflora
Florule E-3

Slide No. 94SR (MZ) E003

1. *Piceapollenites* sp.: R15-25, ↑, 13X

2. *Cedripites* sp. cf. *C. parvus* Norris 1969: R15-8, ↑, 5H

3. *Alisporites* sp. cf. *A. bilateralis* Rouse 1959: R16-33, ↓, 17S

Plate 130

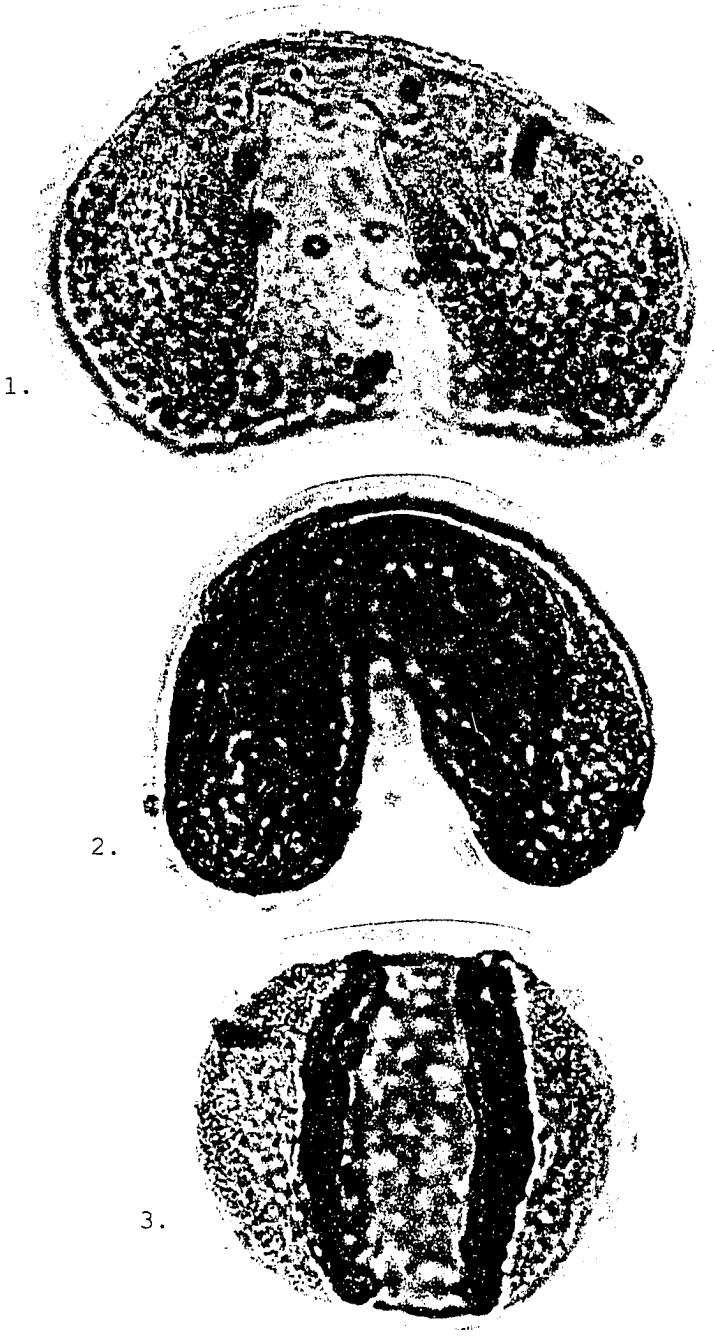


Plate 131

Mazuma Creek Palynoflora
Florule E-3

Slide No. 94SR (MZ) E003

1. *Myrica* sp.: R16-26, ↓, 25-26K

2. *Alnus incana*: R16-27, ↓, 23S

3. *A. incana*: R16-29, ↓, 23Q

4. *A. incana*: R15-14, ↑, 9X

5. Unknown genus: R16-20, ↓, 13B

6. *Aquilapollenites senonicus* (Mchedlishvili) Tschudy and Leopold 1969: R16-23, ↓, 27W

7. *Penetetrapites inconspicuus* Sweet 1986: R16-34, ↓, 6H

8. *Wodehouseia gracile* (Samoilovitch) Pokrovaskaya 1966: R15-16, ↑, 10D

9. *Aquilapollenites* sp. cf. *A. catenireticulatus* Srivastava 1968: R15-7, ↑, 4P-Q

Plate 131

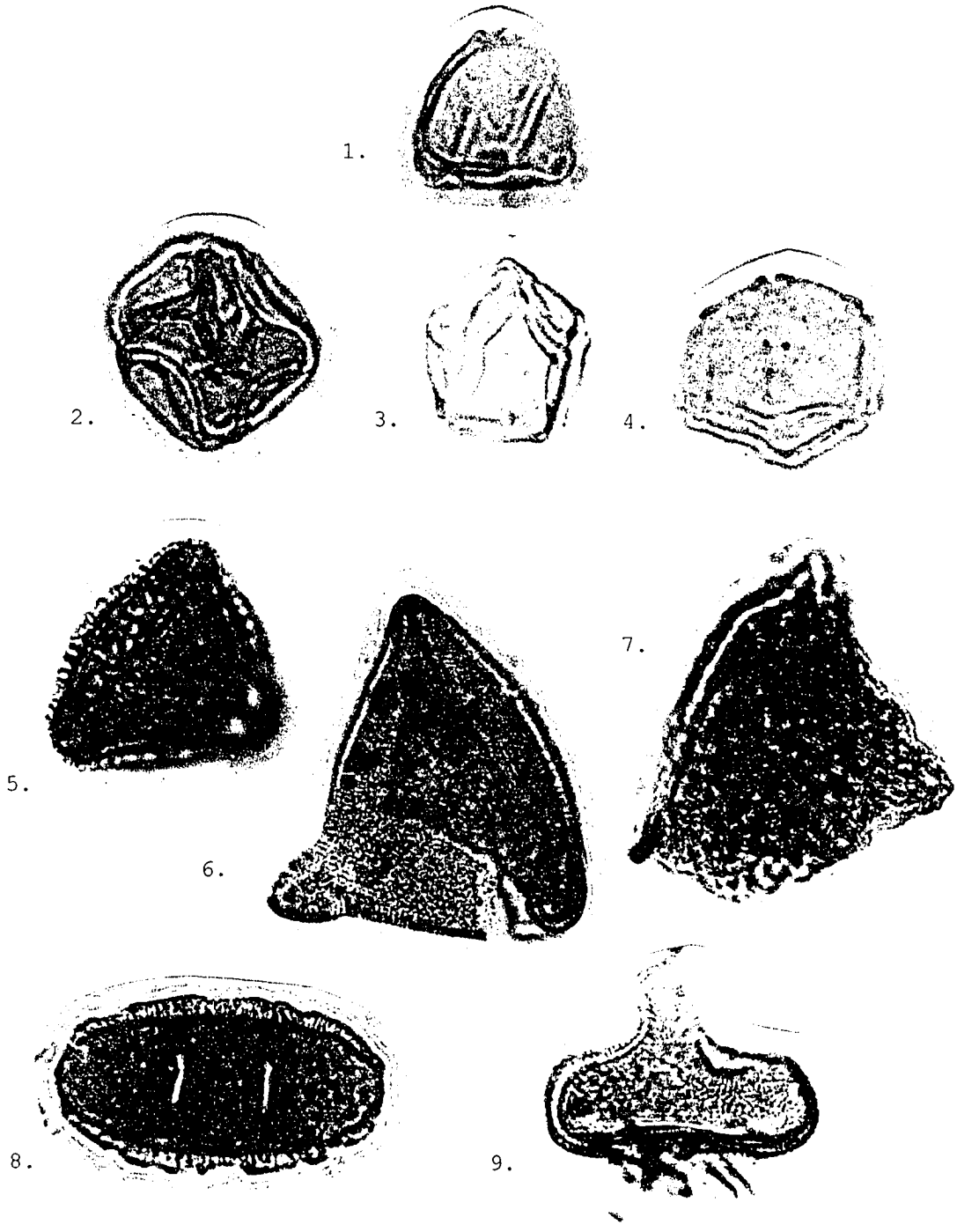


Plate 132

Mazuma Creek Palynoflora
Florule E-6

Slide No. 94SR (MZ) E006

1. *Laevigatosporites* sp.: R16-7, ↓, 24P

2. *Camarozonosporites insignis* Norris 1967: R16-4, ↓, 31G

3. *Retitriletes clavatoides* (Couper) Doring *et al.* 1963: R16-17, ↑, 14T

4. *Deltoidospora* sp.: R16-11, ↑, 1-2M

5. *Cyathidites australis* Couper 1953: R16-13, ↑, 11D

Plate 132

25 µm

Plate 133

Mazuma Creek Palynoflora
Florule E-6

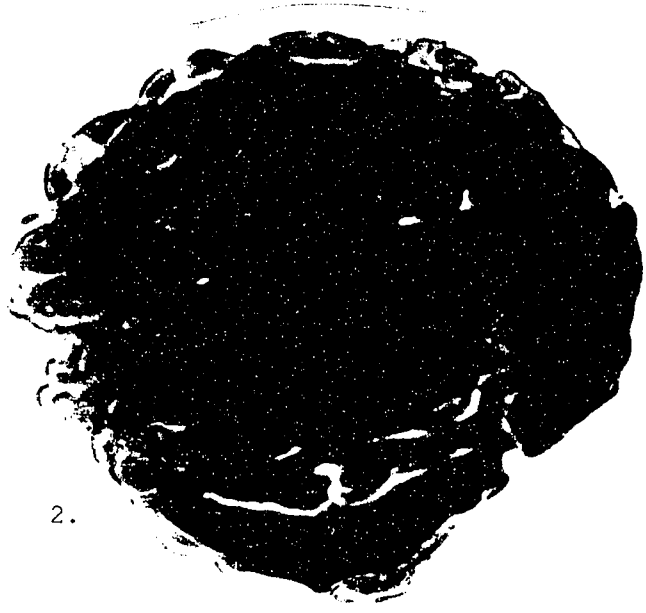
Slide No. 94SR (MZ) E006

1. *Cicatricosisporites* sp.: R16-12, ↑, 8E

2. *C.* sp.: R16-8, ↓, 22-23U

Plate 133

1.



2.

25 µm

Plate 134

Mazuma Creek Palynoflora
Florule E-6

Slide No. 94SR (MZ) E006

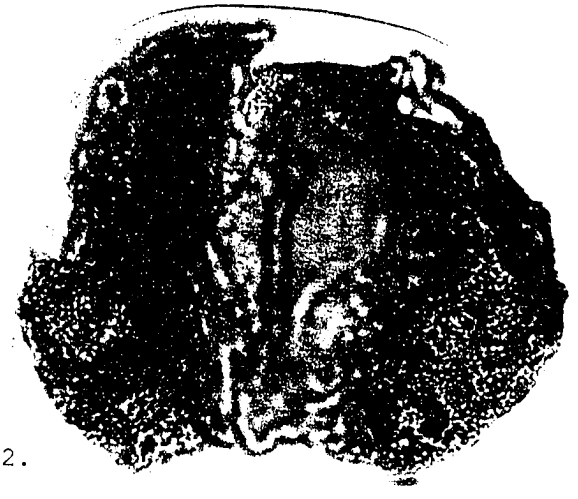
1. *Cedripites* sp.: R16-15, ↑, 13E

2. *Parvisaccites* sp. cf. *P. rugulatus* Brenner 1963: R16-5, ↓, 29M

Plate 134

1.

2.



25 μm

Plate 135

Mazuma Creek Palynoflora
Florule E-6

Slide No. 94SR (MZ) E006

1. *Extraporopollenites* sp.: R16-14, ↑, 13G

2. *Penetetrapites inconspicuus* Sweet 1986: R16-10, ↓, 21B

3. *Spermitites* sp.: R16-9, ↓, 22S

4. *Spermitites* sp.: R16-3, ↓, 32U

5. *Wodehouseia capillata* Wiggins 1976: R16-1, ↓, 36R

Plate 135

APPENDIX F
Photographic Plates

Plate 136

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. cf. *Sequoia* (radial section) Tidwell 1998: R27-16, ↑, 13Q

2. Wood : R27-15, ↑, 11S

3. Wood : R27-14, ↑, 9S

4. Wood : R27-11, ↑, 4P

5. cf. *Taxodium* (Taxodioid crossfield pits) Tidwell 1998: R27-12, ↑, 5M

Plate 136

25 μm

Plate 137

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94Sr (MZ) F002

1. Wood: R27-13, ↑, 8M

2. Wood: R27-8, ↓, 25J

3. cf. *Ginkgo* (radial section) Tidwell 1998: R27-10, ↓, 19P

4. Wood: R27-3, ↓, 31H

Plate 137

Plate 138

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. Wood: R27-9, ↑, 32E

2. Wood: R27-5, ↓, 29S

Plate 138

Plate 139

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. cf. *Pinus* (radial section) Tidwell 1998: R27-4, ↓, 11H-J

2. Wood: R27-6, ↓, 28K

3. Wood: R27-2, ↓, 37J

4. Wood: R27-7, ↓, 27D

Plate 139

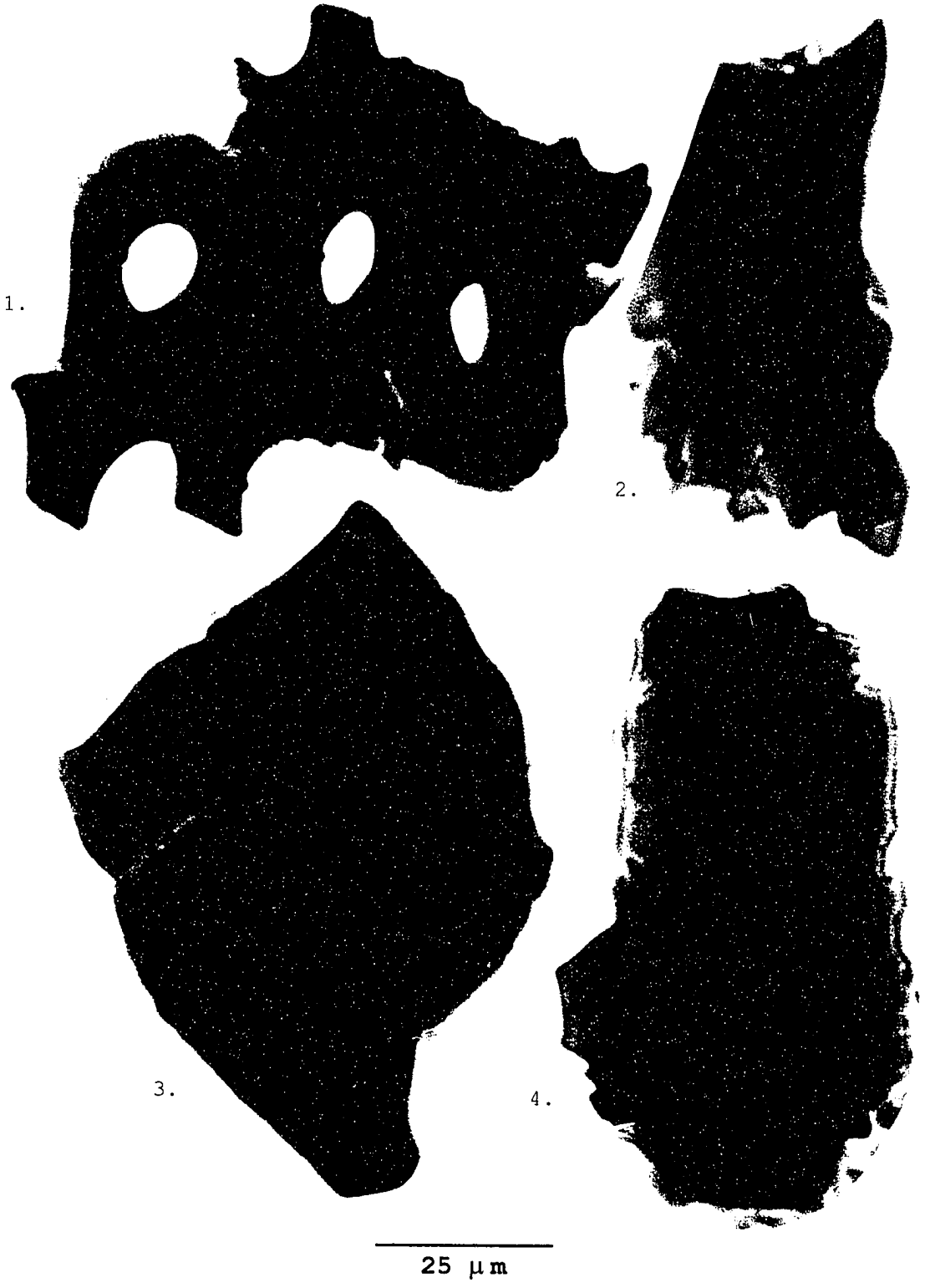


Plate 140

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. *Todisporites minor* Couper 1958: R27-30, ↓, 31Z

2. *Deltoidostoma psilostoma* Rouse 1959: R27-31, ↓, 31K

3. *Undulatisporites fossulatus* Singh 1971: R26-21, ↑, 5-6P

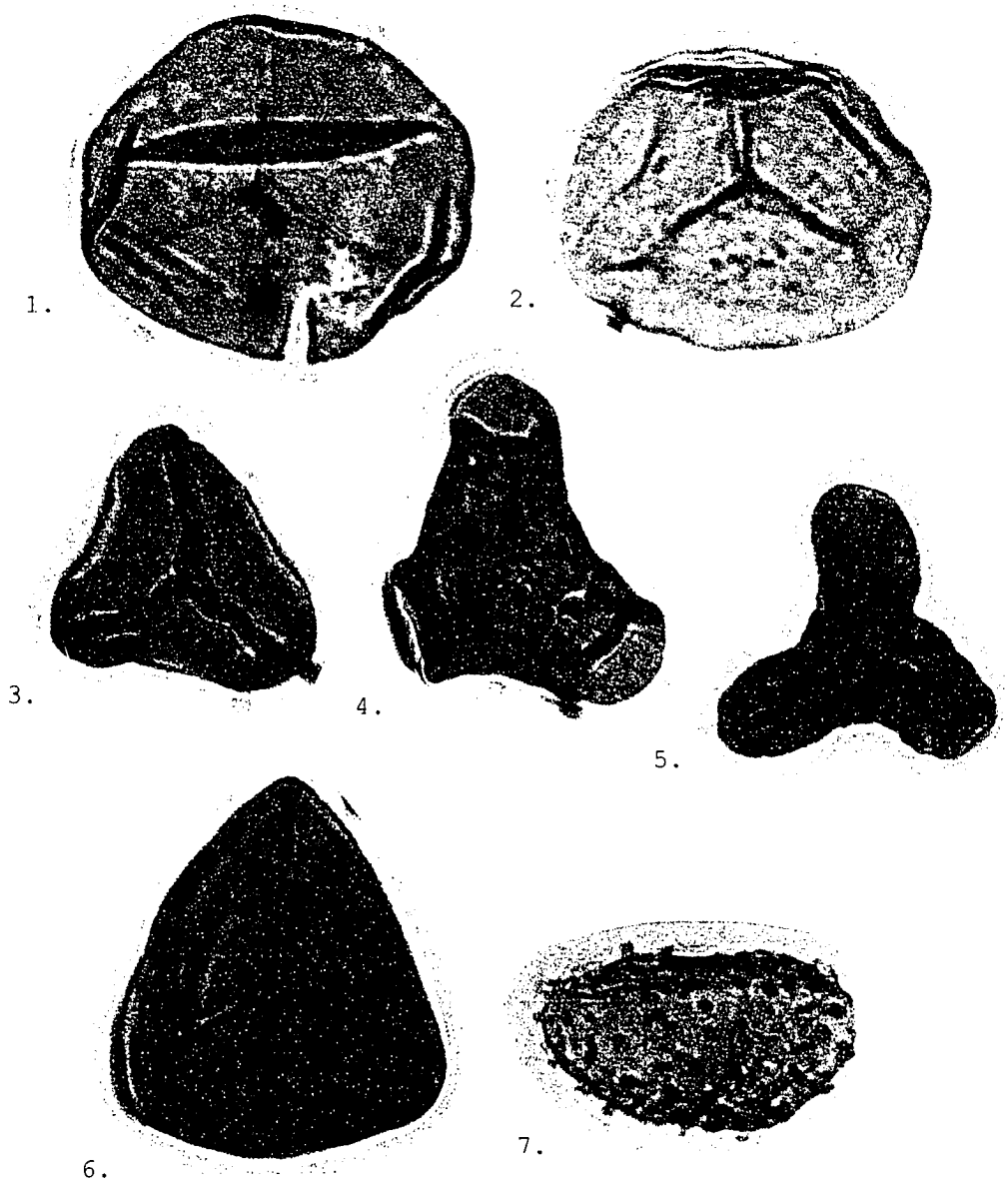
4. *Cibotiumspora juncta* (Kara-Murza) Singh 1983: R27-25, ↓, 33V

5. *Concavissimisporites* sp.: R26-3, ↓, 27-28Y

6. *Cyathidites* sp.: R26-36, ↑, 16U

7. *Schizaeoisporites* sp.: R26-26, ↑, 11Q

Plate 140



25 µm

Plate 141

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. *Polypodiidites* sp.: R27-35, ↓, 29T

2. *Retitriletes subreticulaesporites* (Rouse) Krutzsch 1963: R26-35, ↓, 15V

3. *R. subreticulaesporites*: R26-27, ↑, 11Q

4. *Lycopodiumsporites crassimacerius* Hedlund 1966: R26-30, ↑, 13W

5. *Stereisporites antiquasporites* (Wilson and Webster) Dettmann 1963: R27-29, ↓, 31R

6. *Krauselisporites hastilobatus* Playford 1971: R27-22, ↓, 33R

7. *Trianchoraesporites reticulatis* Schulz 1962: R27-26, ↓, 23Y

8. Unknown genus: R32-37, ↓, 18E-F

Plate 141

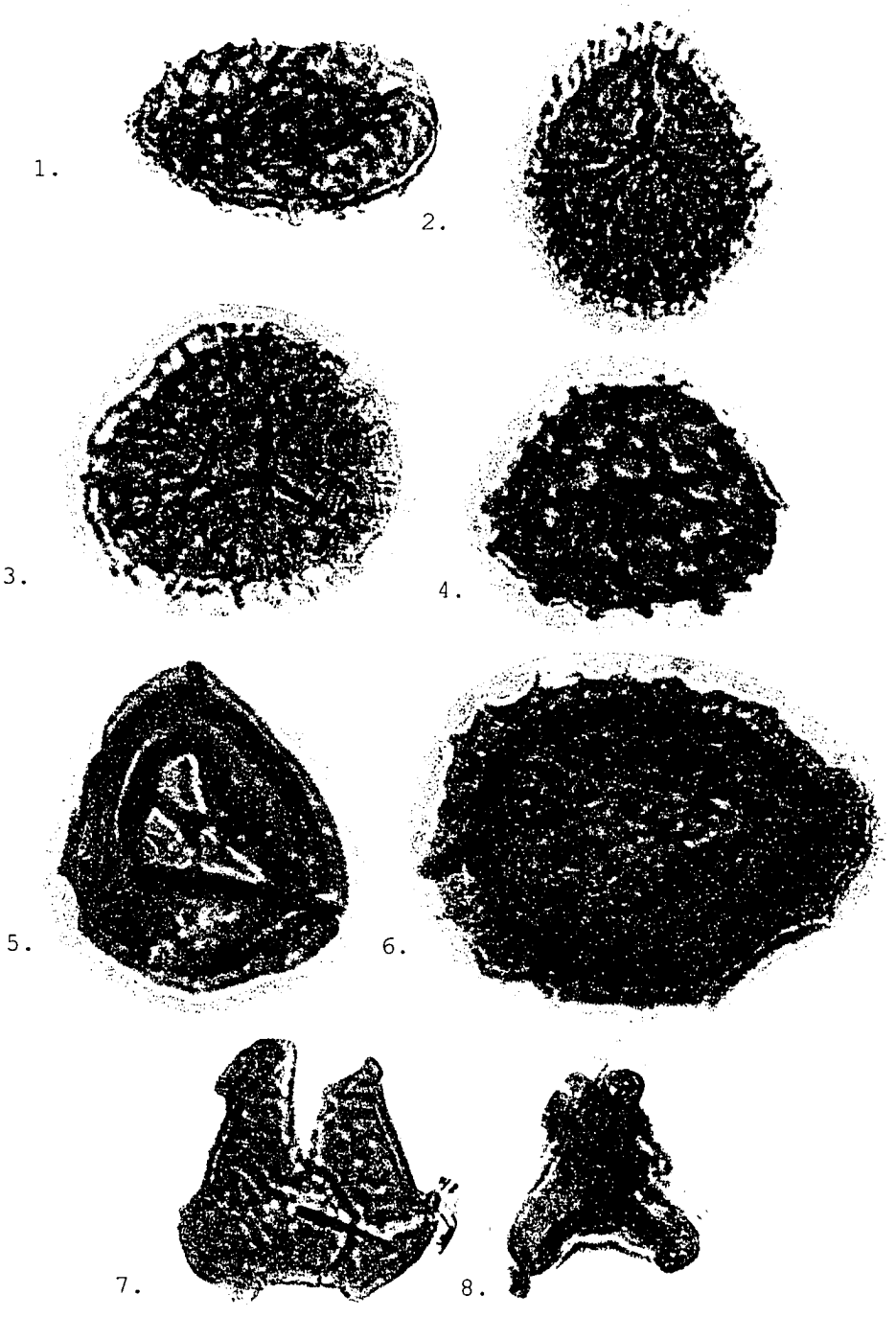


Plate 142

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. *Ornamentifera baculata* Singh 1971: R26-2, ↓, 29J

2. *Concavissimisporites* sp. cf. *C. minor* (Pocock) Delcourt, Dettmann and Hughes 1963: R27-23, ↓, 33T

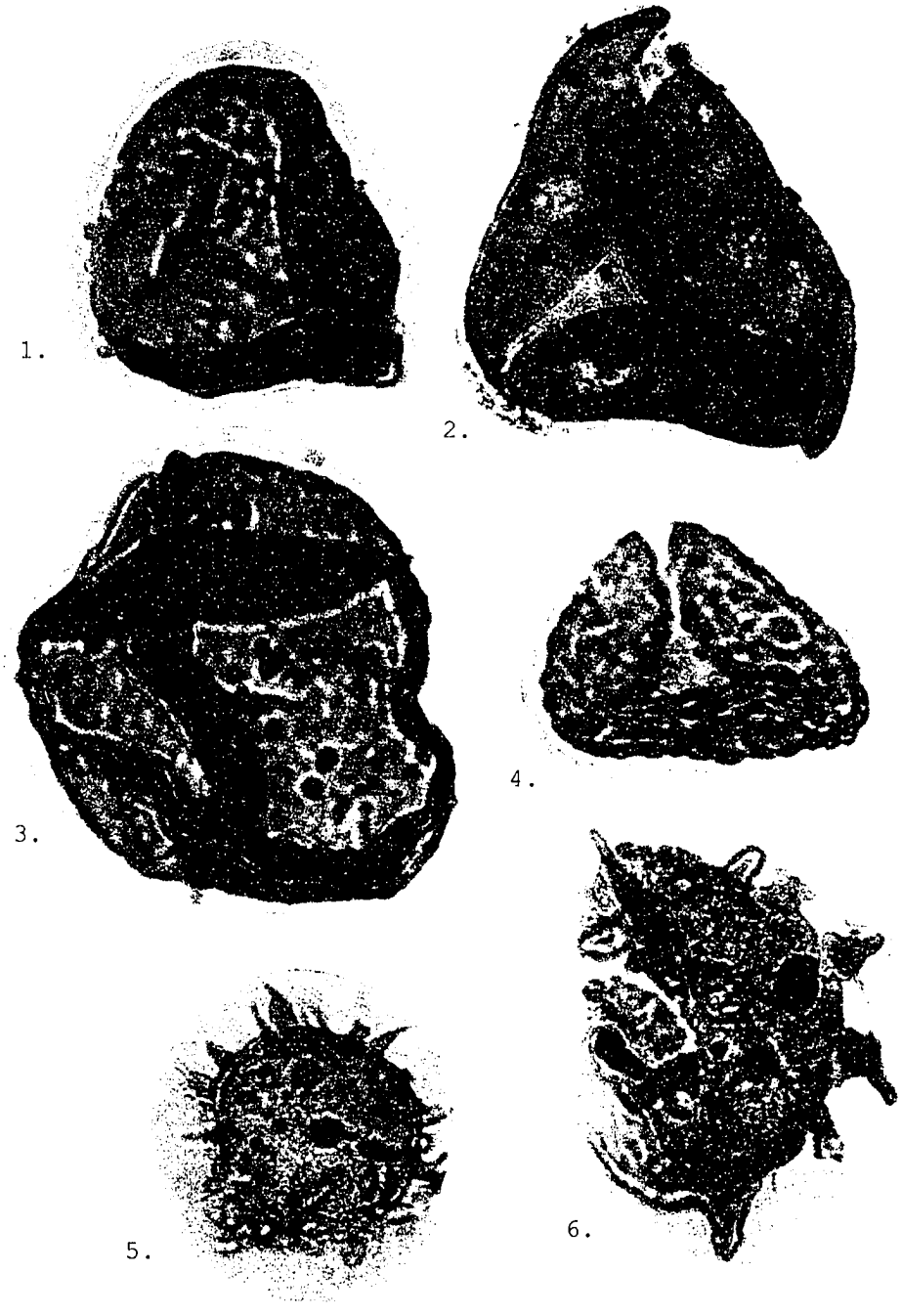
3. *Foraminisporis wonthaggiensis* (Cookson and Dettmann) Dettmann 1963: R27-18, ↓, 36N

4. Verrucosisporites sp.: R26-17, ↑, 3T

5. *Echinosporis* sp.: R26-33, ↑, 15Q

6. *Neoraistrickia* sp.: R26-16, ↑, 2E

Plate 142



25 µm

Plate 143

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. *Pilosisporites* sp.: R27-33, ↓, 13E

2. *Echinatisporis* sp.: R26-13, ↓, 20H

3. *Kaeuselisporites reissingerii* (Harris) Morbey 1975: R26-11, ↓, 22M

4. *Foveosporites crassus* Dorhofer 1977: R26-5, ↓, 28Q

5. *Microreliculatisporites uniformis* Singh 1964: R27-34, ↓, 30H

6. *Foveotriletes palaequestrus* Partridge 1973 : R26-24, ↑, 10D

7. *Foveosporis* sp. cf. *F. linearis* Krutzsch 1959: R26-6, ↓, 27N

Plate 143

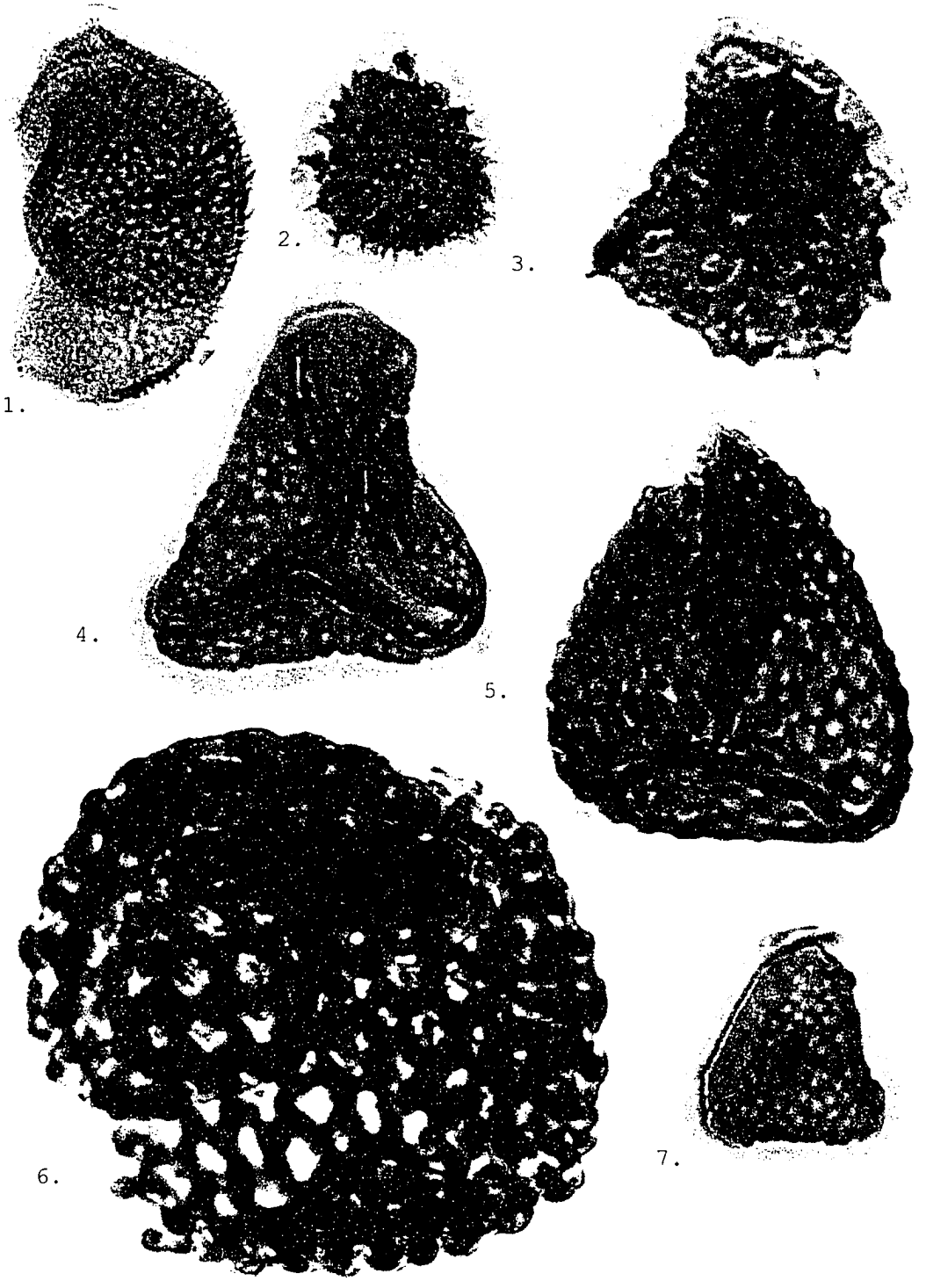


Plate 144

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. *Cicatricosisporites* sp.: R27-17, ↓, 37-38V

2. *Cicatricosisporites* sp. cf. *C. hallei* Delcourt and Sprumont 1955: R26-14, ↓, 19E

3. *Cicatricosisporites* sp. cf. *C. imbricatus* (Markova) Singh 1971: R26-28, ↑, 12C

4. *Cicatricosisporites* sp. cf. *C. annulatus* Archangelsky and Gamerrc 1966: R27-1, ↓, 30J

Plate 144

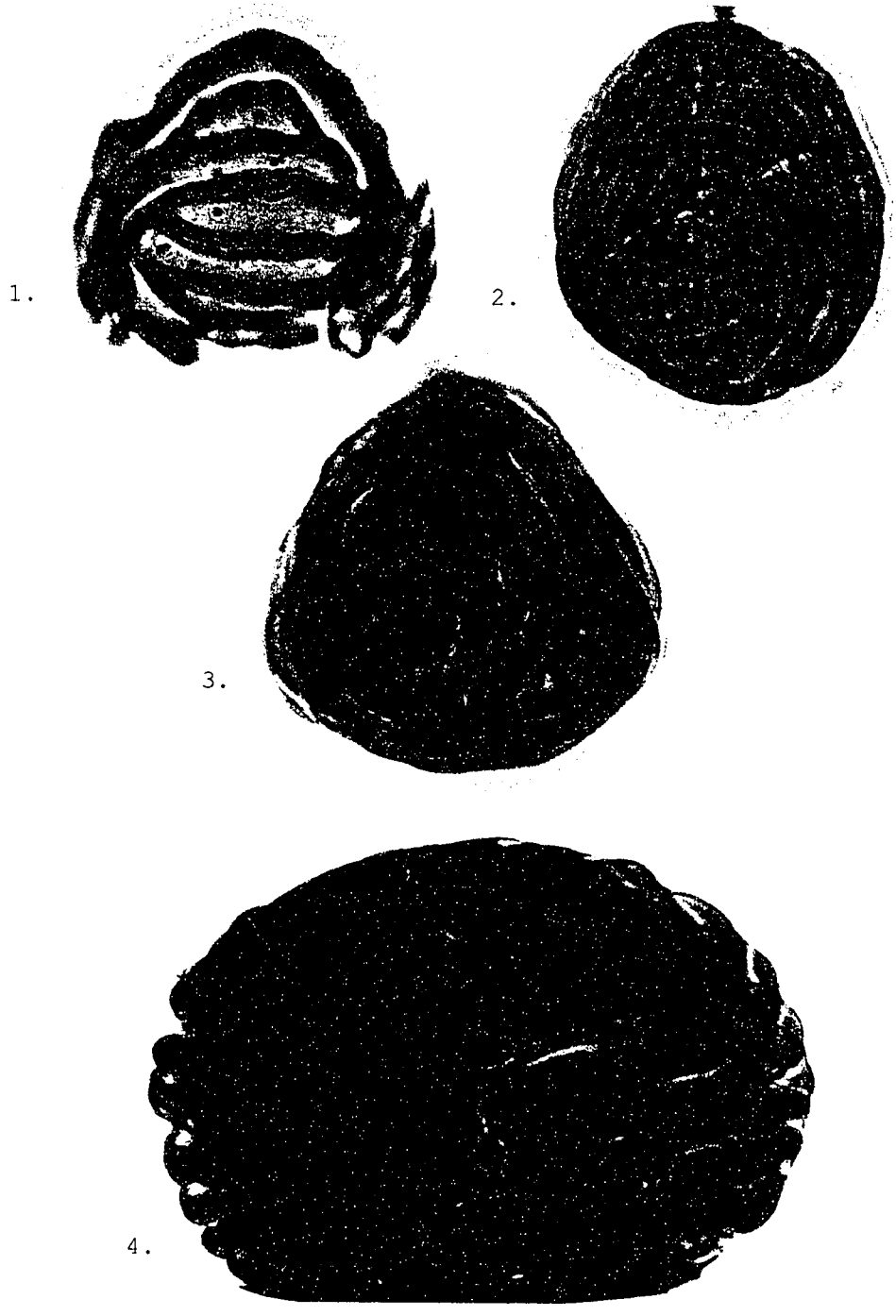


Plate 145

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. cf. *Brevimonosulcites corrugatus* Yu and Zhang 1987: R27-24, ↓, 33V

2. *Polycingulatisporites reduncus* (Bolkhovitina) Playford and Dettmann 1965 : R26-25, ↑, 11R

3. *Ornamentifera echinata* (Bolkhovitina) Bolkhovitina 1966: R26-18, ↑, 4N

4. *Distaltriangulisporites perplexus* (Singh) Singh 1971: R26-19, ↑, 4N

5. *Lycopodiacidites canaliculatus* Singh 1971: R26-22, ↑, 6R

Plate 145

Plate 146

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. *Podocarpidites granulatus* Singh 1971: R27-21, ↓, 34P-Q

2. *Pinuspollenites* sp.: R26-15, ↓, 19K

3. *Cedripites* sp.: R27-36, ↓, 29L

4. *Abiespollenites* sp.: R26-31, ↑, 14L

5. *Parvisaccites* sp.: R26-32, ↑, 15Q

6. *Podocarpidites canadensis* (Pocock) Singh 1971: R26-23, ↑, 9G

Plate 146

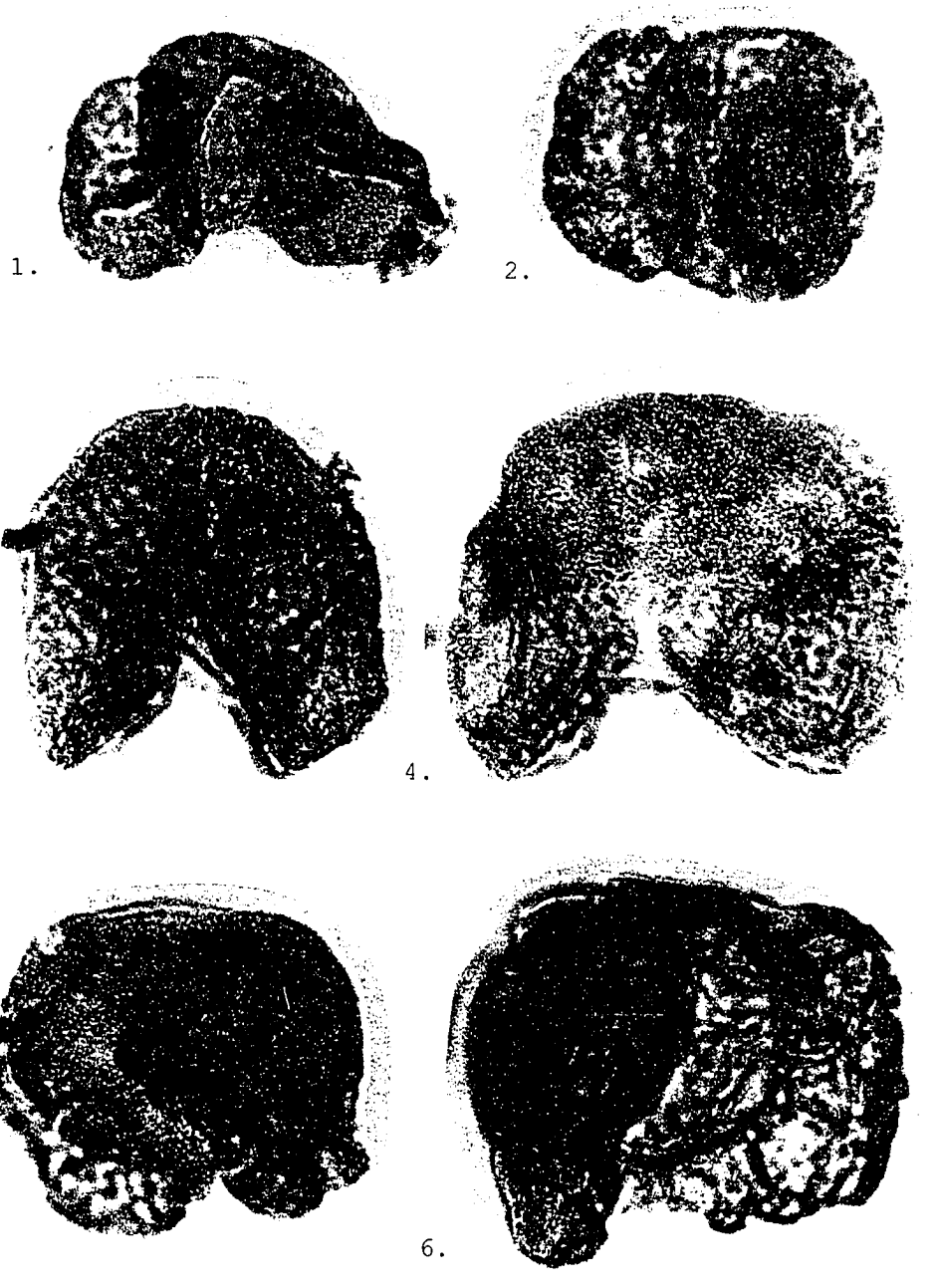


Plate 147

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. *Pinuspollenites constrictus* (Singh) Wingate 1980: R26-10, ↓, 24Q

2. *Alisporites grandis* (Cookson) Dettmann 1963: R26-4, ↓, 27S

3. *Podocarpidites potomacensis* Brenner 1963: R26-14, ↓, 28-29D

4. *P. potomacensis*: R26-7, ↓, 26U

Plate 147

Plate 148

Mazuma Creek Palynoflora
Florule F-2

Slide No. 94SR (MZ) F002

1. *Abietipites* sp.: R27-19, ↓, 35Q

2. *Parvisaccites radiatus* Couper 1958: R27-32, ↓, 31F

3. *Podocarpidites canadensis* (Pocock) Singh 1971: R26-8, ↓, 24-25K

4. *P. canadensis*: R26-9, ↑, 32E

5. *Boehlensipollis* sp.: R26-12, ↓, 20F

6. *Betulapollenites* sp.: R27-28, ↓, 31N

Plate 148

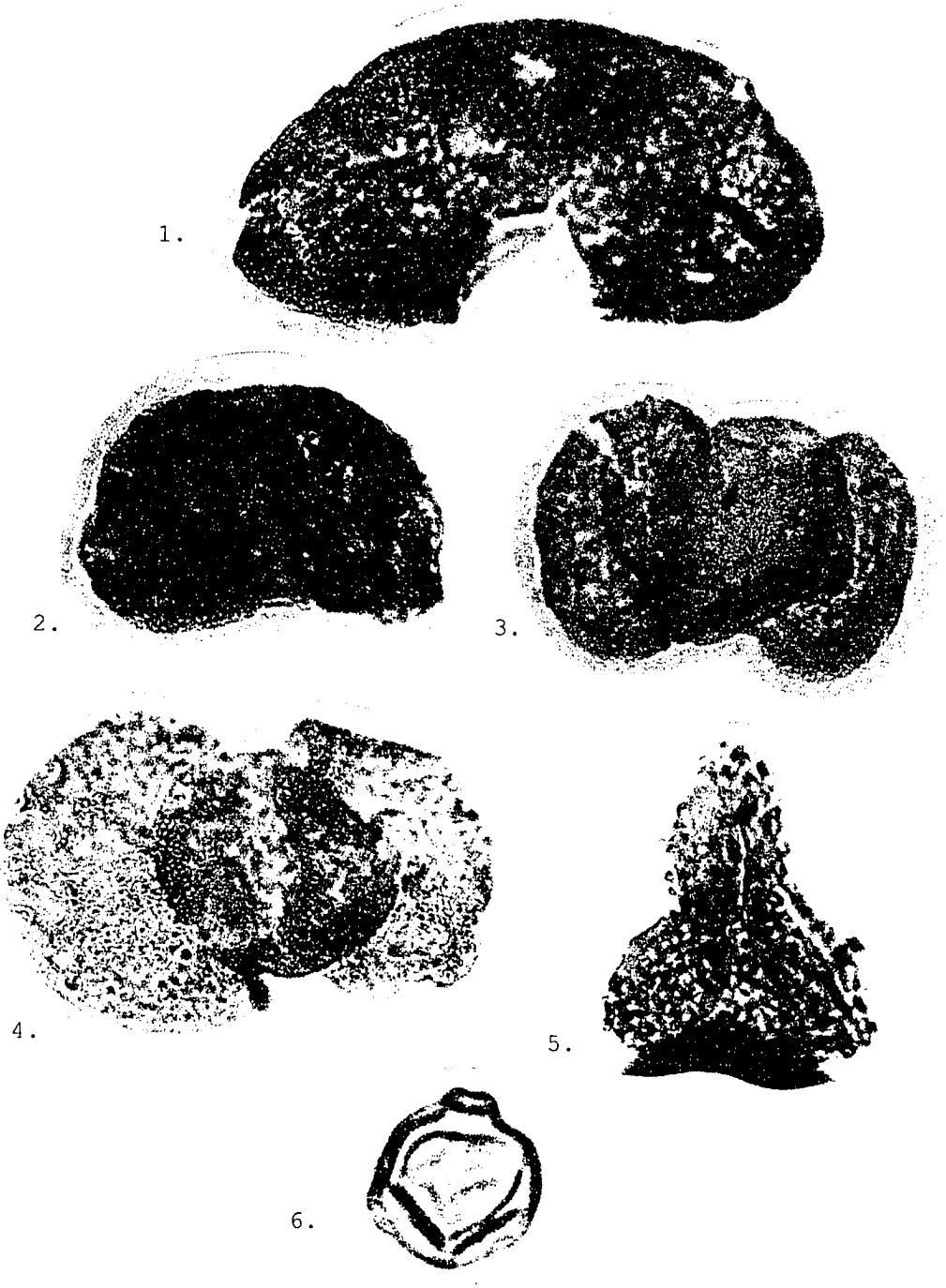


Plate 149

Mazuma Creek Palynoflora
Florule F-3

Slide No. 94SR (MZ) F003

1. Wood: R29-21, ↓, 18G

2. cf. *Podocarpus* (radial section) Tidwell 1998: R29-23, ↑, 1-2G

3. Wood: R29-25, ↑, 8Q

4. Wood: R29-22, ↓, 17L

5. Wood: R29-24, ↑, 5L

Plate 149

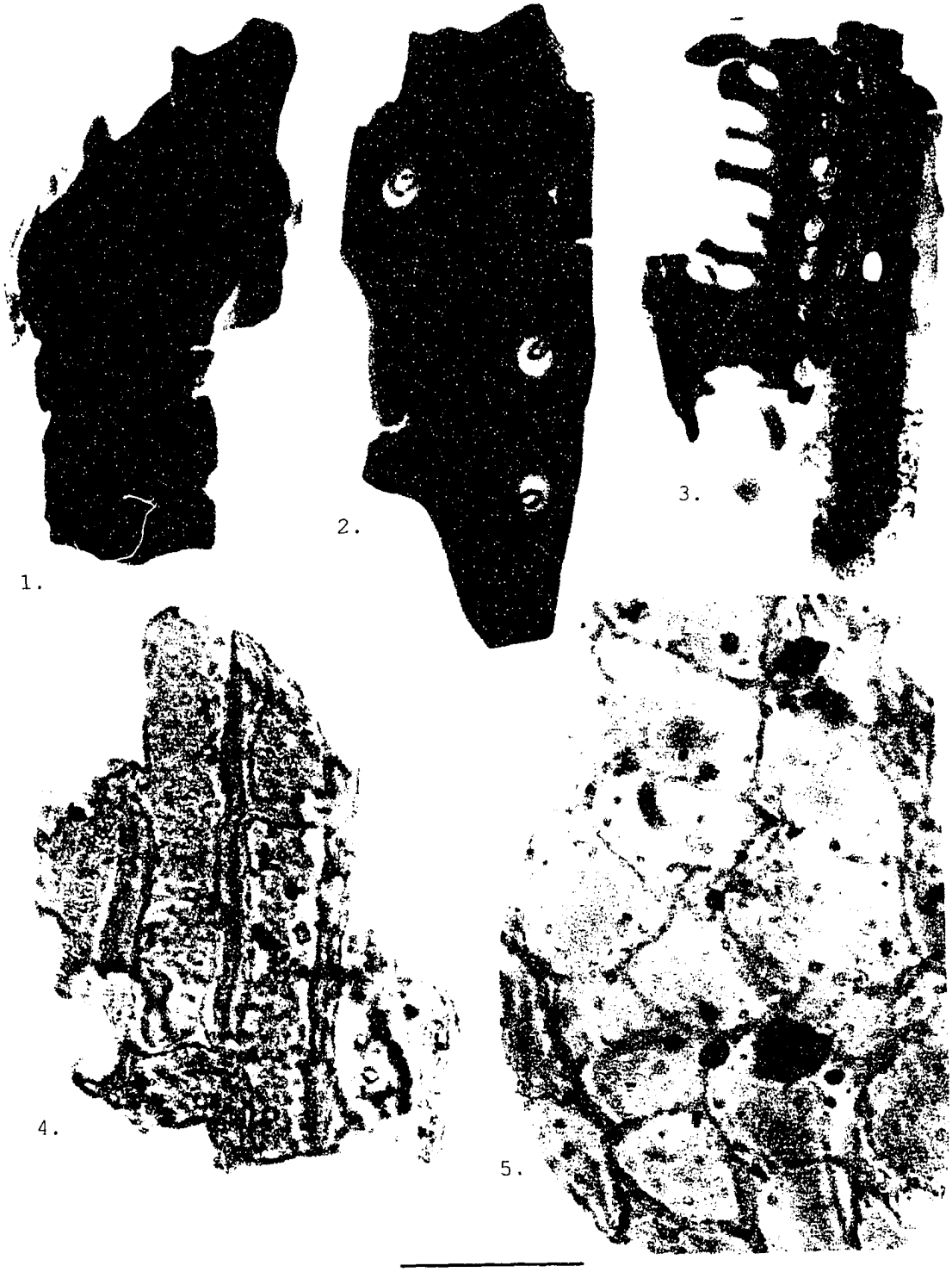


Plate 150

Mazuma Creek Palynoflora
Florule F-3

Slide No. 94SR (MZ) F003

1. *Cyathidites diaphana* (Wilson and Webster) Nichols and Brown 1992: R28-32, ↑, 13-15T

2. *Concavitriletes mesozoicus* Krutzsch 1959: R28-34, ↑, 14M

3. *Cyathidites* sp.: R28-1, ↓, 30R

4. *Gleicheniidites* sp.: R29-30, ↑, 13-14T

5. *Gleicheniidites senonicus* (Ross) Delcourt and Sprumont 1955: R29-32, ↓, 34X

6. *Trianchoraesporites reticulatus* Schulz 1962: R28-16, ↓, 17J

7. *Aequitriradites spinulosus* (Cookson and Dettman) Cookson and Dettman 1961: R28-15, ↓, 19H

Plate 150

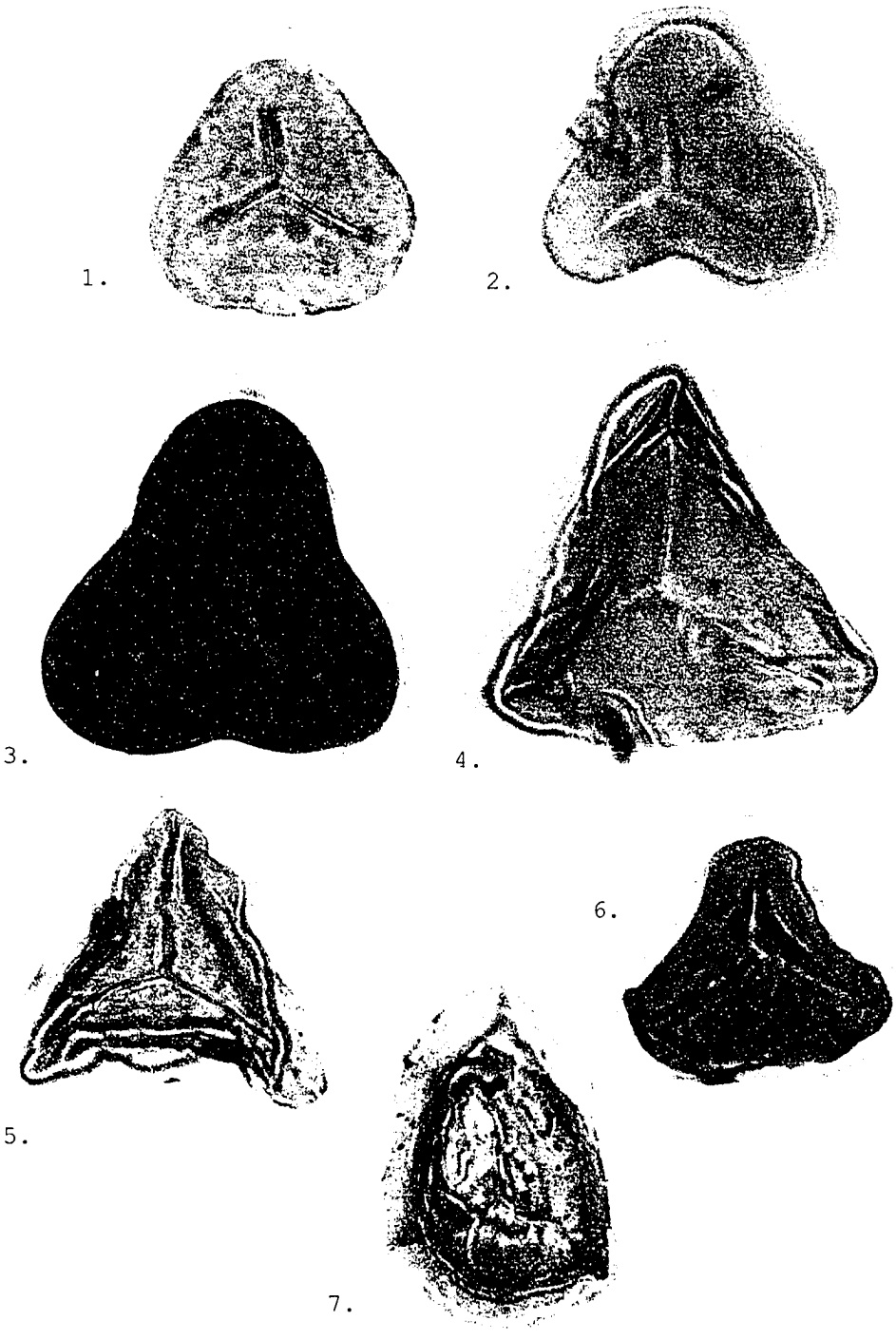


Plate 151

Mazuma Creek Palynoflora
Florule F-3

Slide No. 94SR (MZ) F003

1. *Polypodiites* sp.: R28-35, ↑, 13-14E

2. *Lycopodiumsporites marginatus* Singh 1964: R28-2, ↓, 29U

3. *Retitriletes subreticulaesporites* (Rouse) Krutzsch 1963: R28-31, ↑, 13P

4. *Leptolepidites verrucatus* Couper 1953: R29-35, ↓, 32-33V

5. Unknown genus: R29-26, ↓, 18J

6. *Camarozonosporites insignis* Norris 1967: R29-31, ↓, 36Q-R

7. *Todisporites minor* Couper: R28-8, ↓, 25M-N

8. *Ornamentifera echinata* (Bolkhovitina) Bolkhovitina 1966: R28-22, ↑, 4N

9. *Echinatisporis* sp.: R28-11, ↓, 22P

Plate 151

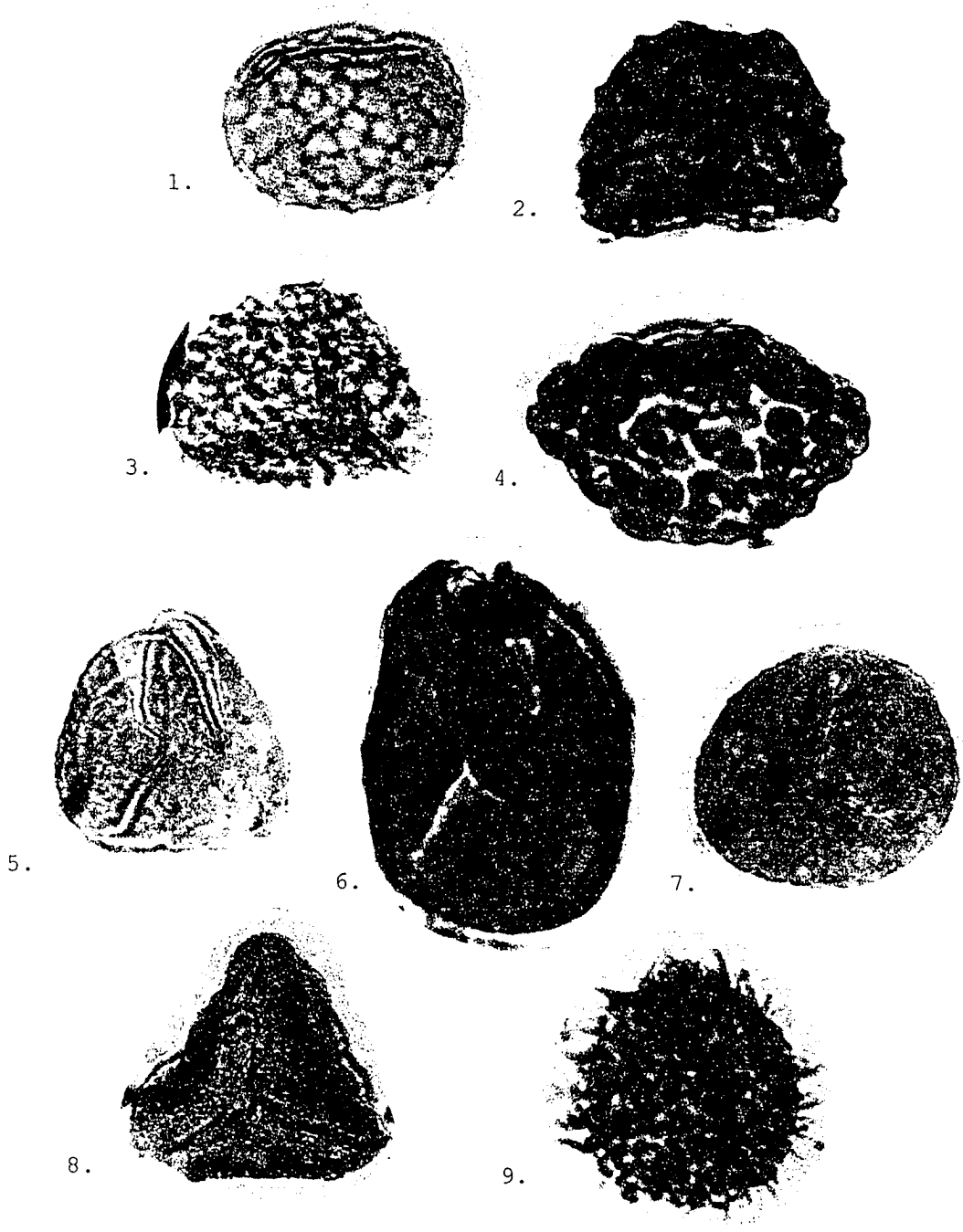


Plate 152

Mazuma Creek Palynoflora
Florule F-3

Slide No. 94SR (MZ) F003

1. *Cicatricosisporites augustus* Singh 1971: R28-12, ↓, 21-22N

2. *Cicatricosisporites radiatus* Krutzsch 1959: R29-33, ↓, 34-35T

3. *Cicatricosisporites* sp.: R28-13/14, ↓, 20D

4. *Cicatricosisporites* sp.: R28-20, ↑, 35T

5. *Cicatricosisporites* sp.: R28-7, ↓, 26H-J

Plate 152

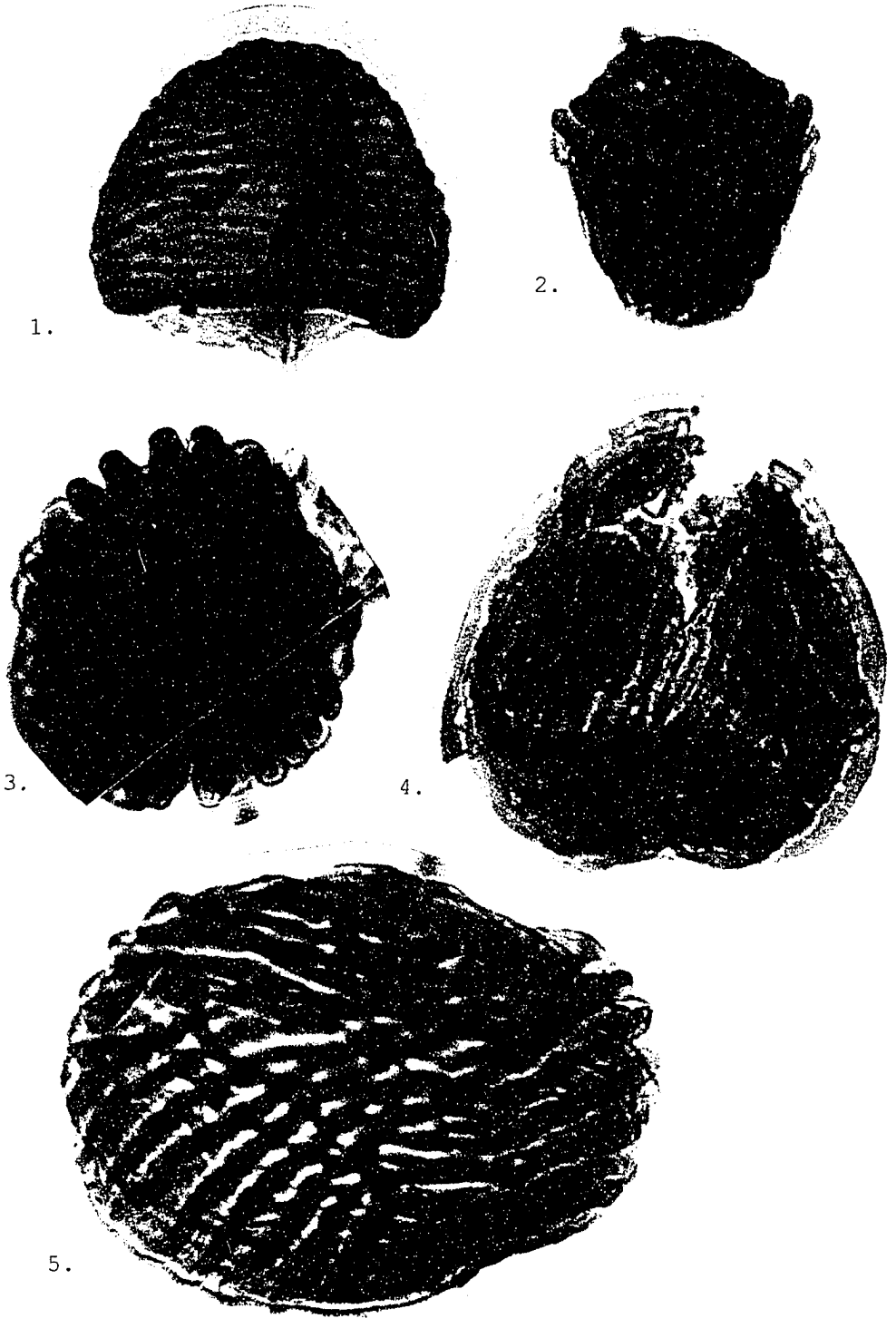


Plate 153

Mazuma Creek Palynoflora
Florule F-3

Slide No. 94SR (MZ) F003

1. *Foveosporites subtriangularis* (Brenner) Doring 1966: R28-21, ↑, 3V

2. *Cicatricosisporites ornatus* Srivastava 1972: R28-5, ↓, 27G-H

3. *Psilatriletes radiatus* (Brenner) Doring 1966: R28-28, ↑, 8V

4. *Polycingulatisporites reduncus* (Bolkhovitina) Playford and Dettmann, 1965: R28-27, ↓, 18Q

5. *Distaltriangulisporites perplexus* (Singh) Singh 1971: R28-30, ↑, 12R

6. *Distaltriangulisporites mutabilis* Singh 1971: R28-29, ↑, 10H

Plate 153

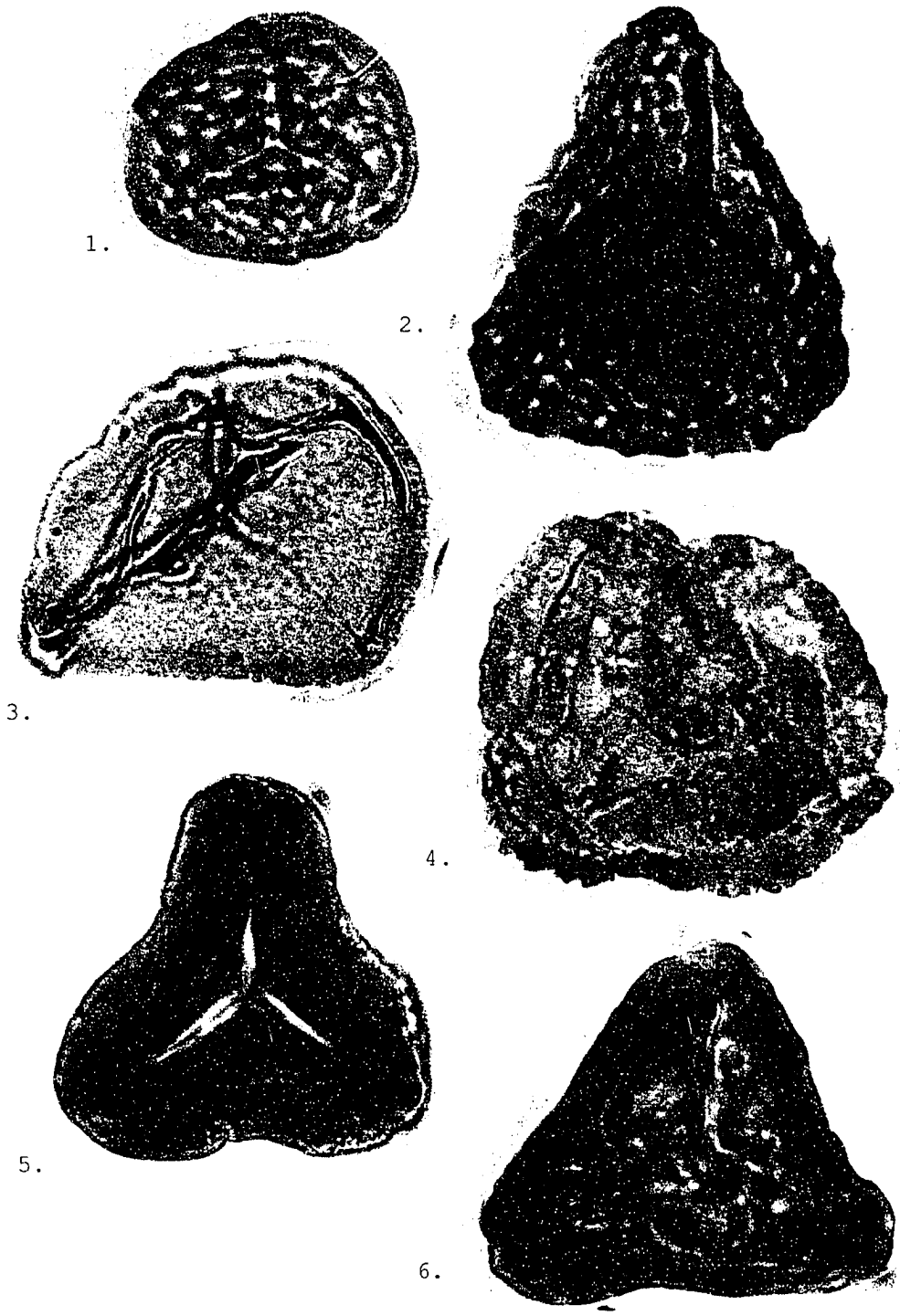


Plate 154

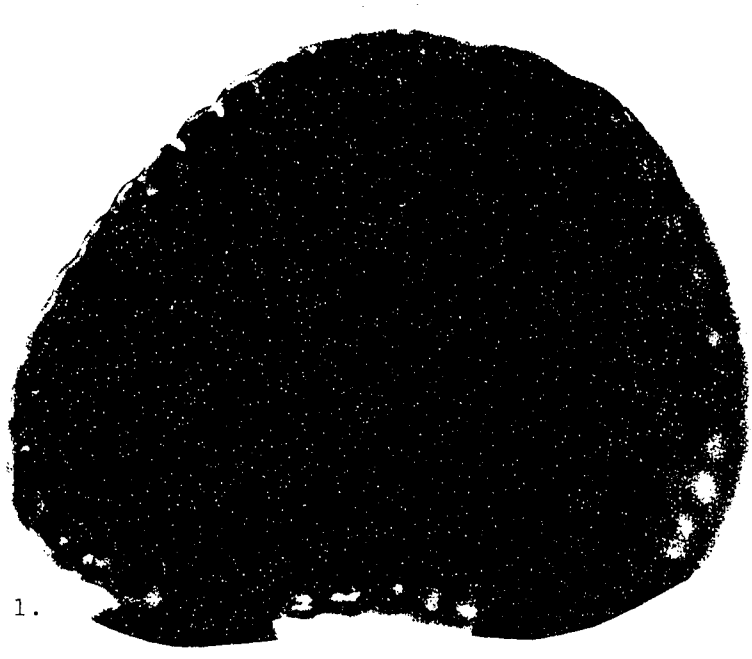
Mazuma Creek Palynoflora
Florule F-3

Slide No. 94SR (MZ) F003

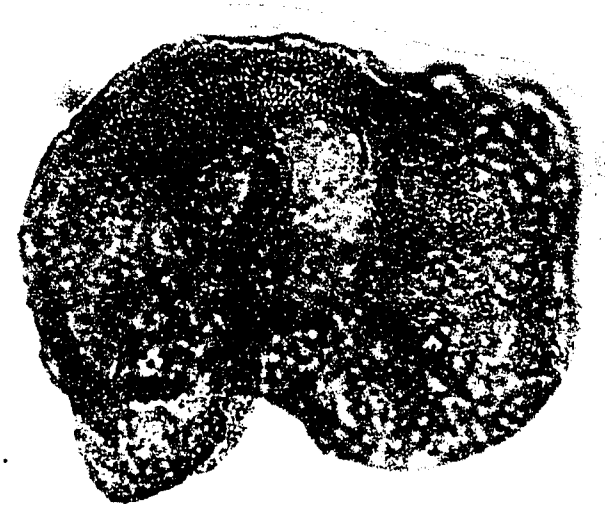
1. *Foveasporis linearis* Krutzsch 1959: R29-34, ↓, 34P

2. *Podocarpidites canadensis* (Pocock) Singh 1971: R28-33, ↑, 13V

Plate 154



1.



2.

25 μm

Plate 155

Mazuma Creek Palynoflora
Florule F-3

Slide No. 94SR (MZ) F003

1. *Pinuspollenites* sp.: R29-37, ↓, 31K

2. *Rugubivesiculites* sp.: R28-10, ↓, 22-23G

3. *Podocarpidites granulatus* Singh 1971: R28-19, ↓, 17J

4. *Podocarpidites minisculus* Singh 1964: R28-24, ↑, 7L

5. *Piceapollenites* sp.: R28-25, ↑, 7-8J

Plate 155

25 µm

Plate 156

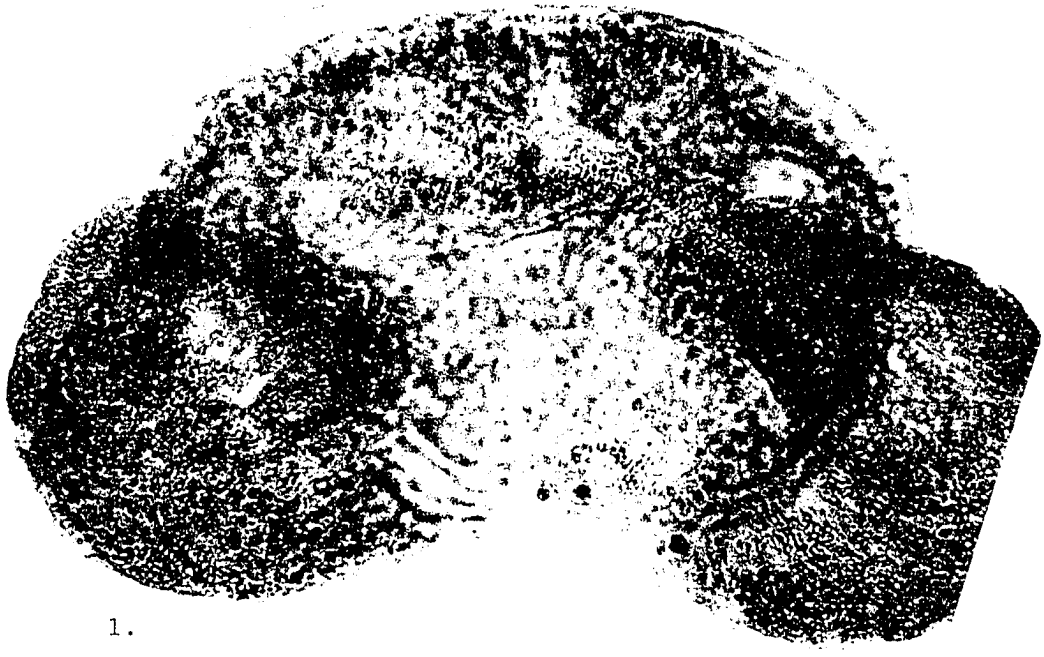
Mazuma Creek Palynoflora
Florule F-3

Slide No. 94SR (MZ) F003

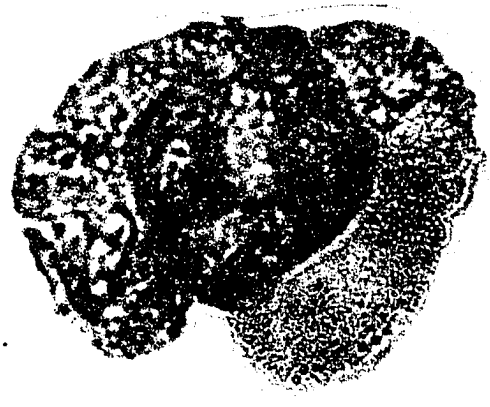
1. *Pityosporites elongatus* var. *grandis* Tschudy 1973: R28-26, ↑, 8E

2. *Podocarpidites potomacensis* Brenner 1963: R29-36, ↓, 31G

Plate 156



1.



2.

25 µm

Plate 157

Mazuma Creek Palynoflora
Florule F-3

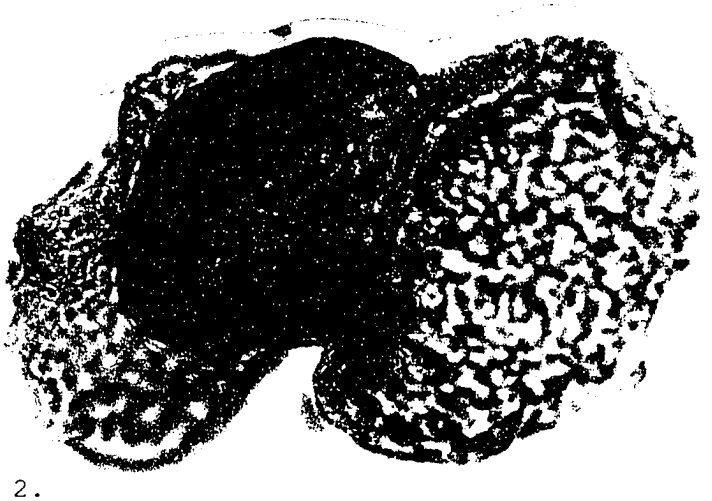
Slide No. 94SR (MZ) F003

1. *Podocarpidites canadensis* (Pocock) Singh 1971: R28-9, ↓, 25R

2. *Platysaccus* sp.: R28-33, ↑, 13V

Plate 157

1.



2.

25 µm

Plate 158

Mazuma Creek Palynoflora
Florule F-4

Slide No. 94SR (MZ) F004

1. *Undulatisporites fossulatus* Singh 1971: R29-15, ↑, 8R

2. *Cyathidites minor* Couper 1953: R29-5, ↓, 30Q

3. *Lycopodiumsporites* sp.: R30-31, ↓, 36V

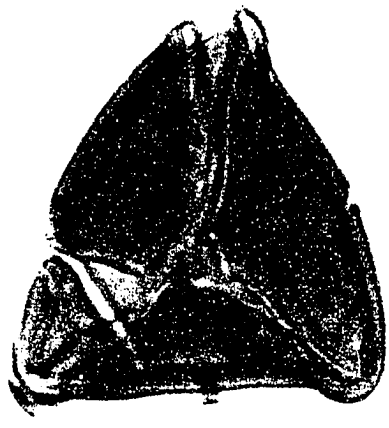
4. *Cicatricosisporites* sp.: R29-13, ↑, 4V

5. *Osmundacidites wellmanii* Couper 1953: R29-1, ↓, 32M

6. *Verrucosisporites* sp.: R29-16, ↑, 11P

Plate 158

1.



2.

3.

4.

5.

6.

25 µm

Plate 159

Mazuma Creek Palynoflora
Florule F-4

Slide No. 94SR (MZ) F004

1. *Microreticulatisporites uniformis* Singh 1964: R29-8, ↓, 17J

2. *Leptolepidites verrucatus* Couper 1953, cluster of three spores: R29-9, ↑, 1M

3. *Biretisporites psilatus* (Groot and Penny) Dettmann 1963: R29-2, ↓, 31E-F

4. *Cicatricosisporites* sp.: R30-33, ↓, 35N

5. *Cicatricosisporites* sp.: R30-32, ↓, 35-36L

6. *Taurocusporites segmentatus* Stover 1962: R29-17, ↑, 11L

Plate 159

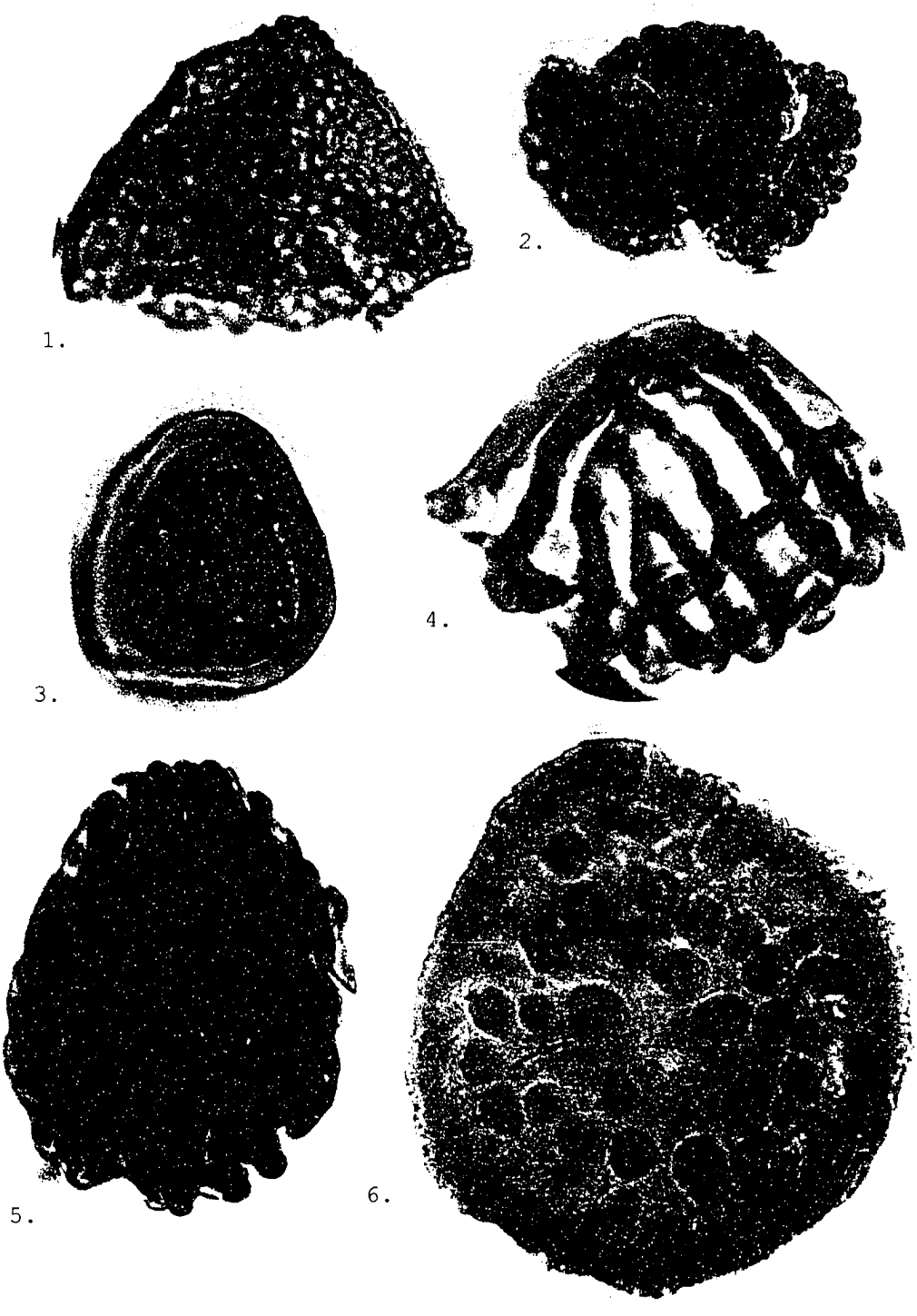


Plate 160

Mazuma Creek Palynoflora
Florule F-4

Slide No. 94SR (MZ) F004

1. *Pityosporites alatipollenites* (Rouse) Singh 1964: R29-12, ↑, 4M

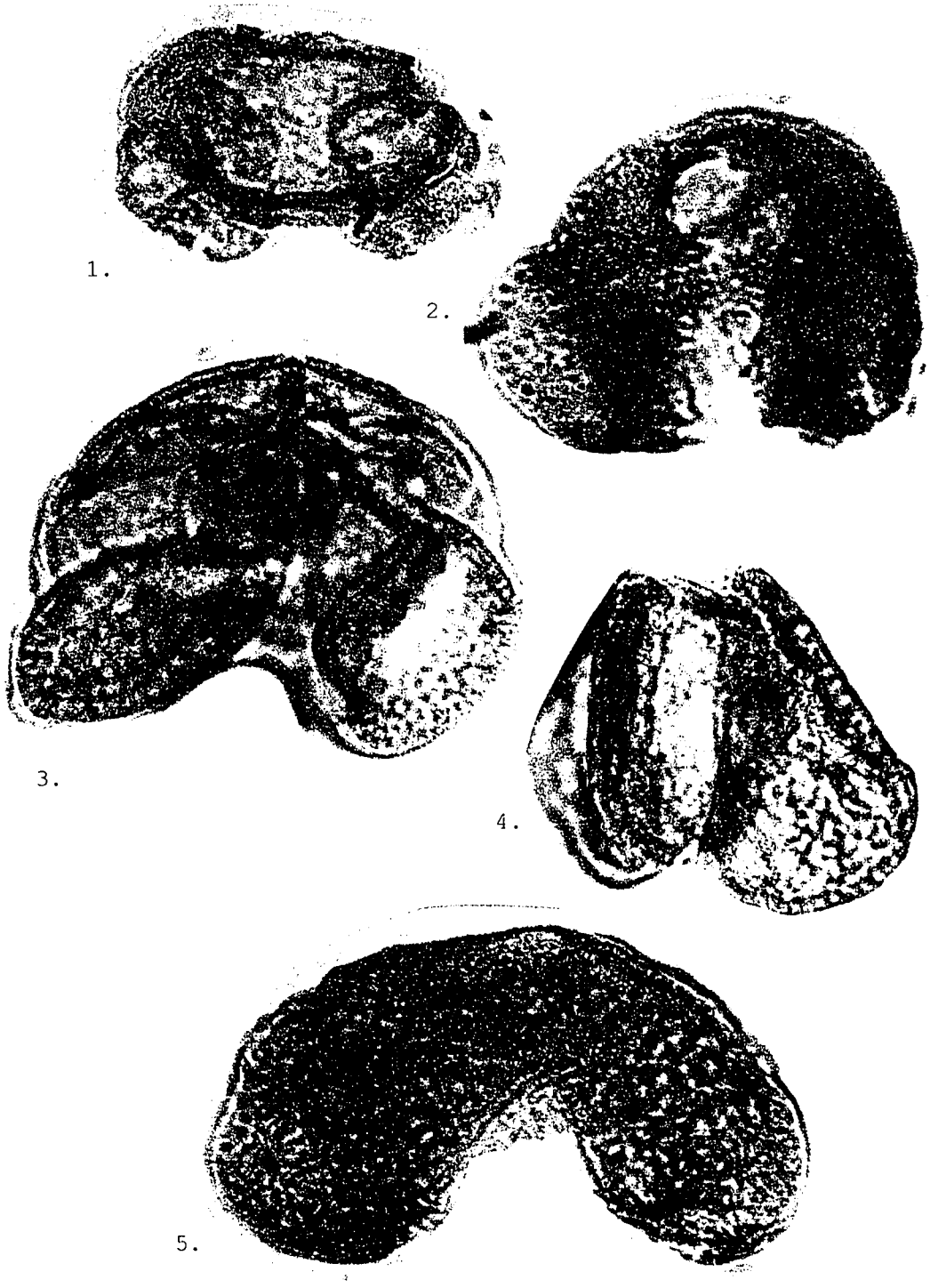
2. *Pinuspollenites* sp.: R30-37, ↓, 32S

3. *Piceapollenites* sp.: R29-7, ↓, 18H

4. *Rugubivesiculites* sp. cf. *R. reductus* Pierce 1961: R29-3, ↓, 30U

5. *Abietipites* sp.: R29-14, ↑, 6R-S

Plate 160



25 μm

Plate 161

Mazuma Creek Palynoflora
Florule F-4

Slide No. 94SR (MZ) F004

1. *Extraporopollenites* sp. A: R29-11, ↑, 3K

2. *Ulmoideipites herbidicus* (Simpson) Sweet 1986: R29-4, ↓, 30Q

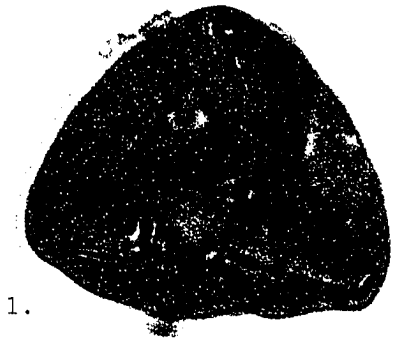
3. cf. *Proteacidites retusus* Anderson 1960: R30-35, ↓, 34W

4. *Tricolpites reticulatus* Cookson 1947: R29-19, ↑, 13D-E

5. *Aquilapollenites spinulosus* Funkhouser 1961: R29-10, ↑, 2S

6. *Aquilapollenites* sp. cf. *A. polaris* Funkhouser 1961: R29-18, ↑, 12P

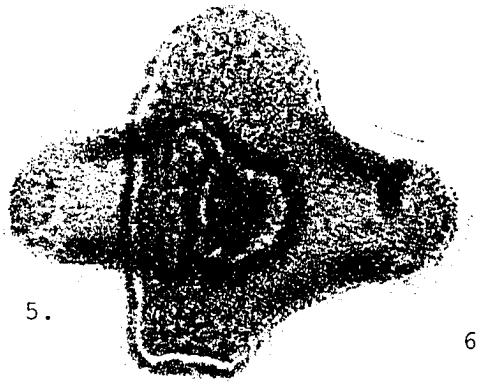
Plate 161


1.


2.


3.


4.


5.


6.

25 μm

Plate 162

Mazuma Creek Palynoflora
Florule F-5

Slide No. 94SR (MZ) F005

1. *Laevigatosporites* sp.: R30-19, ↑, 5Y

2. *Cyathidites australis* Couper 1953: R30-25, ↑, 8N

3. *Deltoidospora halli* Miner 1935: R30-12, ↓, 21R

4. *Biretisporites psilatus* (Groot and Penny) Dettmann 1963: R30-14, ↓, 17-18H

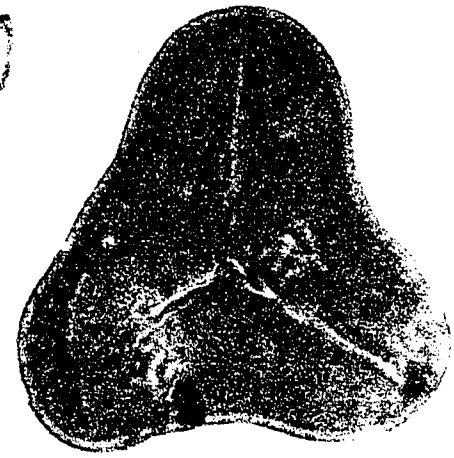
5. *Deltoidospora* sp.: R30-17, ↑, 4Y

6. *Dictophyllidites* sp.: R30-29, ↑, 13S

7. *Gleicheniidites circinidites* (Cookson) Brenner 1963: R30-16, ↑, 2V

Plate 162

1.



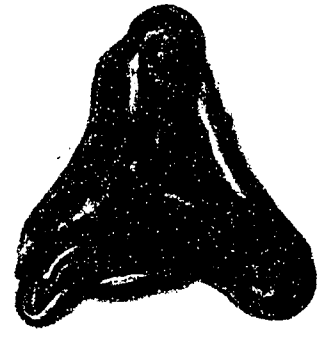
2.

3.

4.

5.

6.



7.

25 μm

Plate 163

Mazuma Creek Palynoflora
Florule F-5

Slide No. 94SR (MZ) F005

1. Retitriletes subreticulaesporites (Rouse) Krutzsch 1963: R30-6, ↓, 31C

2. *Echinatisporis* sp.: R30-24, ↑, 7V

3. *Lycopodiumsporites crassimacerius* Hedlund 1966: R30-21, ↑, 5-6P

4. Unknown genus: R30-11, ↓, 24-25E

5. *Stereisporites antiquasporites* (Wilson and Webster) Dettmann 1963: R30-10, ↓, 26D

6. *Triporoletes radiatus* (Dettmann) Playford 1971: R30-15, ↑, 1Q

7. *Taurocusporites segmentatus* Stover 1962: R30-27, ↑, 12P

Plate 163

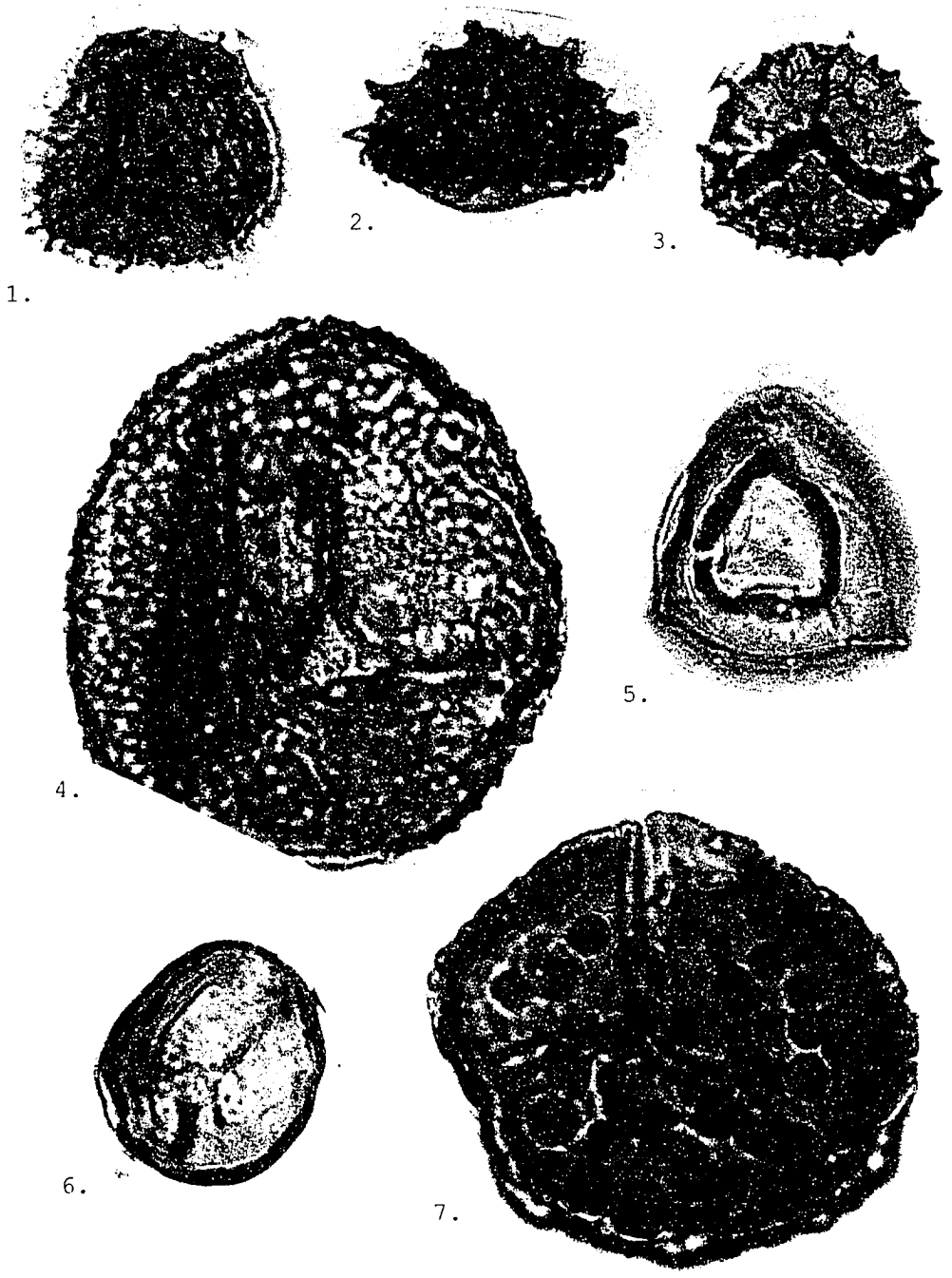


Plate 164

Mazuma Creek Palynoflora
Florule F-5

Slide No. 94SR (MZ) F005

1. *Podocarpidites canadensis* Singh 1971: R30-23, ↑, 6-7V

2. *Pityosporites elongatus* var. *grandis* Tschudy 1973: R30-30, ↑, 15S

3. *Pinuspollenites* sp.: R30-2, ↓, 34B-C

Plate 164

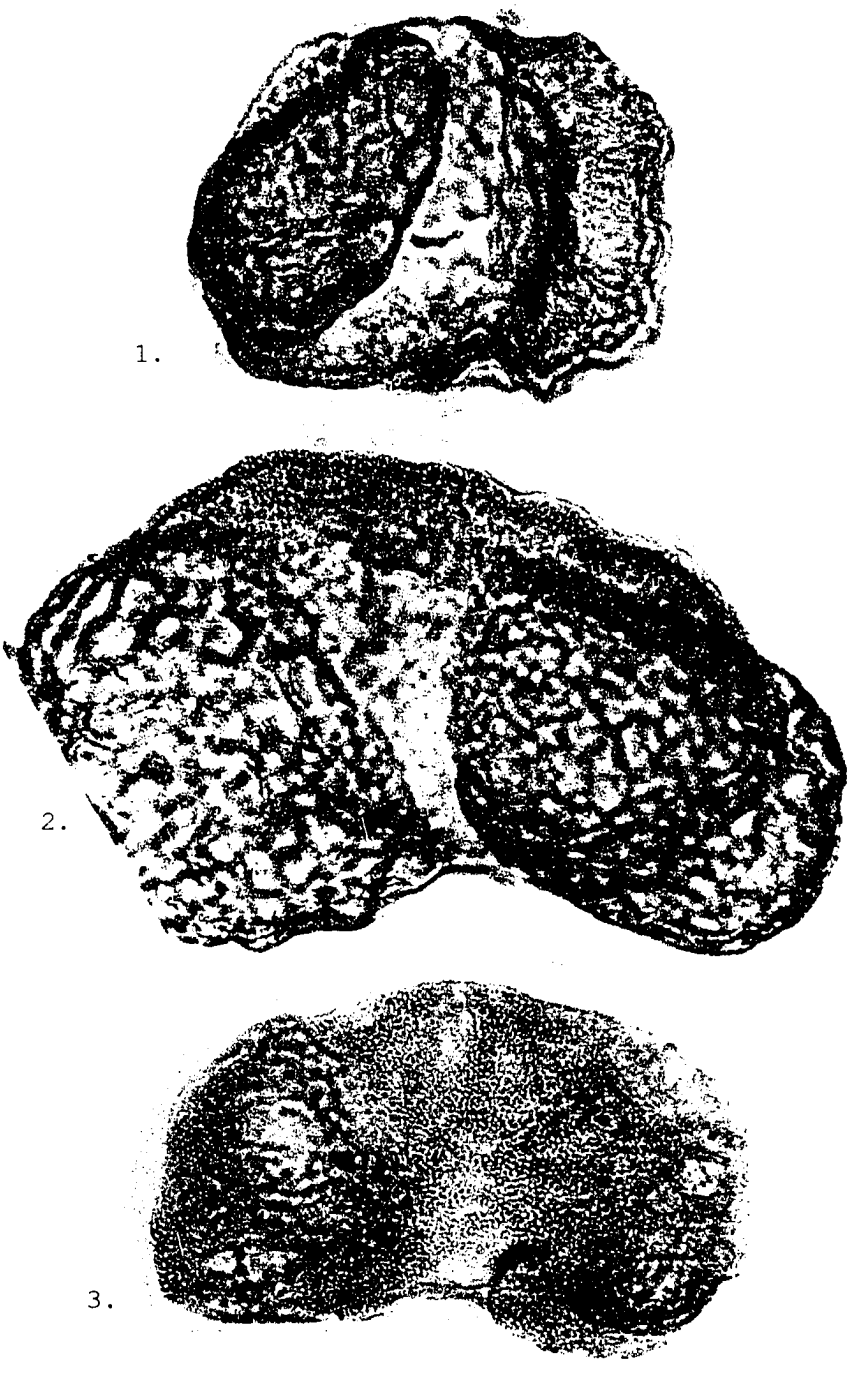


Plate 165

Mazuma Creek Palynoflora
Florule F-5

Slide No. 94SR (MZ) F005

1. *Proteacidites thalmanni* Anderson 1960: R30-1, ↓, 13K

2. *Cranwellia rumseyensis* Srivastava 1966: R30-3, ↓, 35H

3. *C. rumseyensis*: R30-4, ↓, 37L

4. Unknown genus: R30-8, ↓, 29U

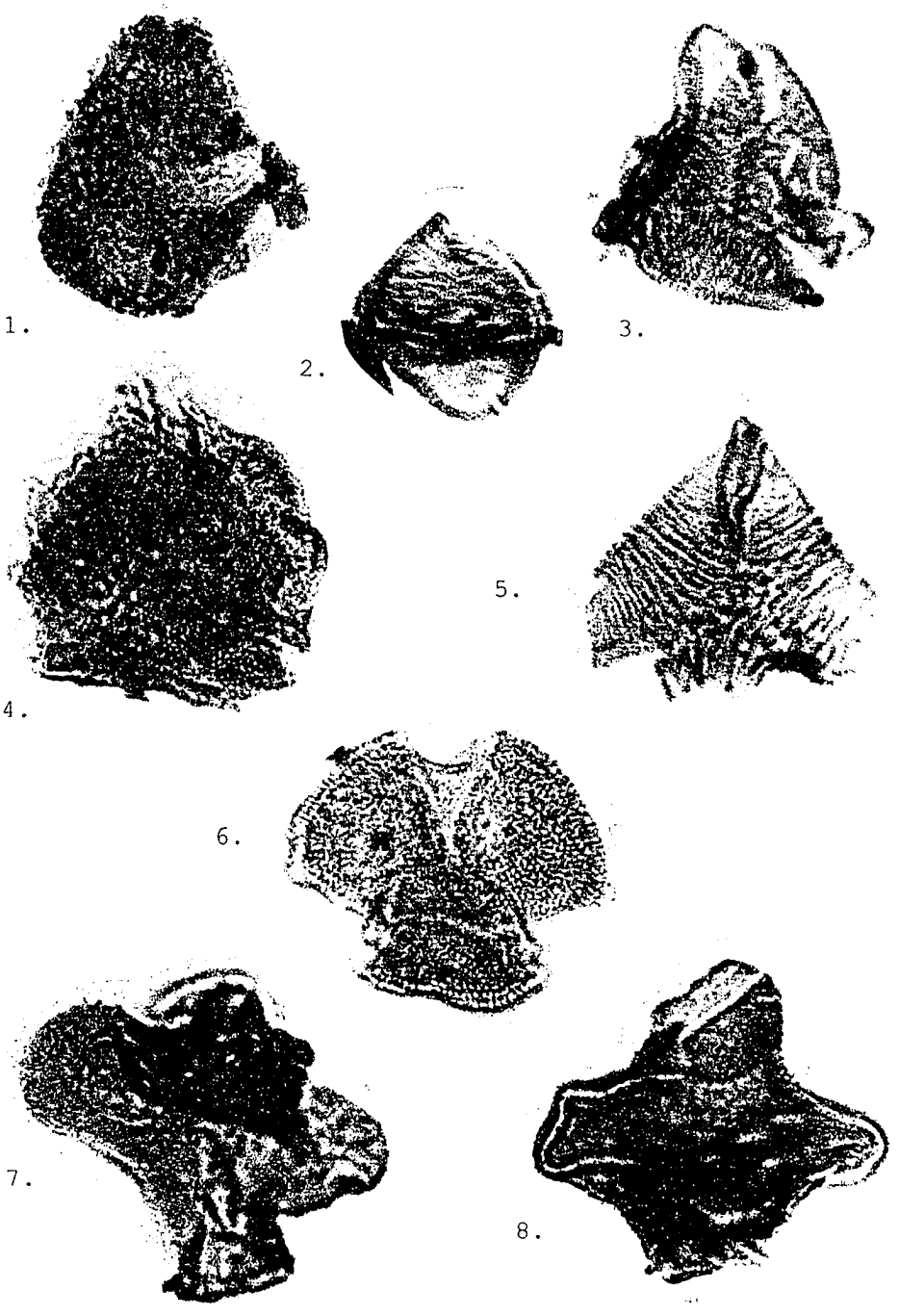
5. *Striatellipollis radiata* (Krutzsch) Sweet 1986: R30-7, ↓, 29U

6. *Tricolpites reticulatus* Cookson 1949: R30-13, ↓, 20L

7. *Aquilapollenites augustus* Srivastava 1969: R30-26, ↑, 9V

8. *Aquilapollenites spinulosus* Funkhouser 1961: R30-20, ↑, 5-6X

Plate 165



APPENDIX G
Photographic Plates

Syncline Mountain Palynomorphs

POLLEN

	Genus	Species
1	*Abietineaepollenites*	sp.
2	cf. *Alisporites*	*bilateralis*
3	*Aquilapollenites*	*notabile*
4	*Aquilapollenites*	*senonicus*
5	*Aquilapollenites*	*spinulosus*
6	cf. *Cedripites*	sp.
7	*Cranwellia*	*striata*
8	*Cycadopites*	*reticulataus*
9	*Ephedrapites*	sp.
10	*Extratriporopollenites*	sp.
11	*Liliacidites*	*inaequalis*
12	*Mancicorpus*	*albertensis*
13	*Mancicorpus*	*rostratus*
14	*Mancicorpus*	cf. *tripodiformis*
15	*Piceapollenites*	sp.
16	*Pityosporites*	*constrictus*
17	*Podocarpidites*	*canadensis*
18	*Podocarpidites*	*granulatus*
19	*Podocarpidites*	*multesimus*
20	*Podocarpidites*	*potomacencis*
21	*Proteacidites*	*auratus*
22	*Quercoidites*	*sternbergi*
23	*Rugubivesiculites*	cf. *reductus*
24	cf. *Rugubivesiculites*	sp.
25	*Taxodiaceapollenites*	*hiatus*
26	Triporate	sp.

Plate 166

Syncline Mountain Palynoflora

Slide No. 39: 96SR 001(2)

1. *Ephedrapites* sp.: R2-30a, ↓, 7U

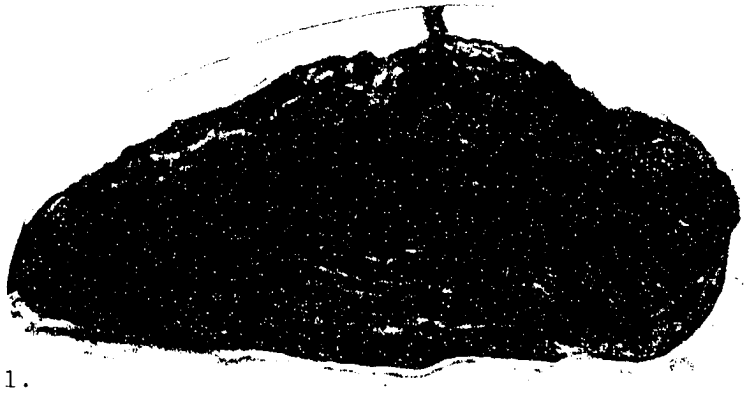
Slide No. 39: 96SR 001(1)

2. *Cycadopites reticulatus* (Nilsson) Cornet and Traverse 1975: R1-4a, ↑, 9F-G

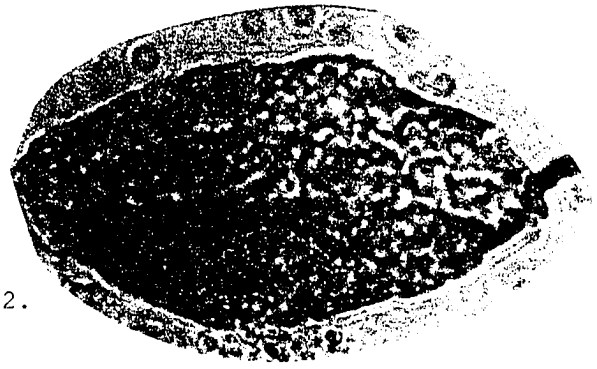
3. *Taxodiaceapollenites hiatus* (Potonié) Kremp 1949: R2-34a, ↓, 29R-S

4. *Piceapollenites* sp.: R2-33a, ↓, 28N-M

Plate 166

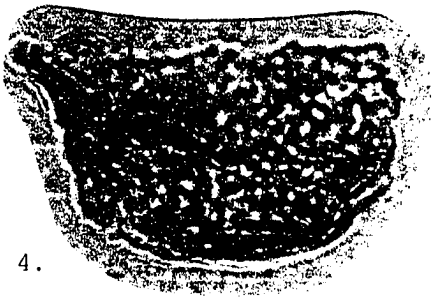


1.



2.

3.



4.

25 µm

Plate 167

Syncline Mountain Palynoflora

Slide No. 40: 96SR 002(1)

1. *Podocarpidites canadensis* Pocock 1962: R2-17a, ↓, 34R

Slide No. 39: 96SR 001(1)

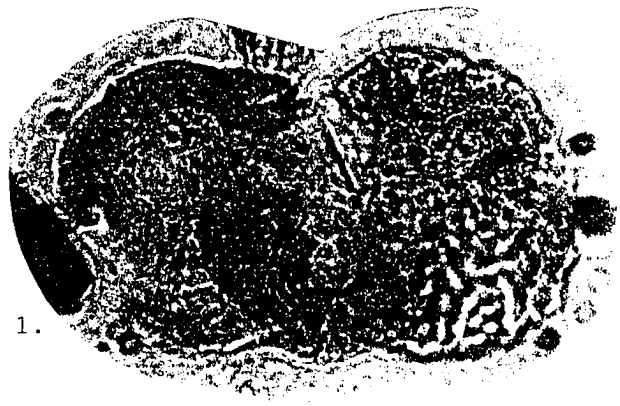
2. *Podocarpidites granulatus* Singh 1971: R2-36a, ↓, 35S- T

3. *Rugubivesiculites* sp. cf. *R. reductus* Pierce 1961: R1-7a, ↑, 10-11H

Slide No. 39: 96SR 001(2)

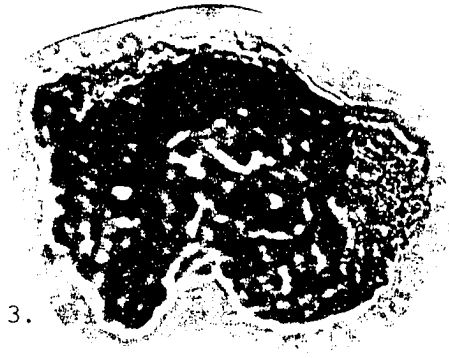
4. *Podocarpidites potomacencis* Brenner 1963: R2-28a, ↑, 8L

Plate 167

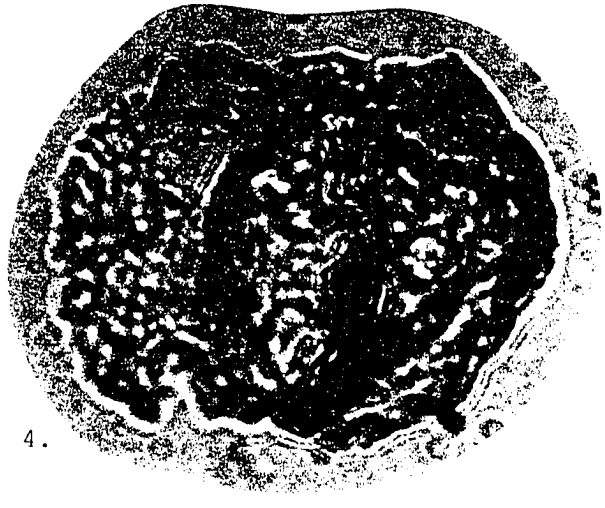


1.

2.



3.



4.

25 µm

Plate 168

Syncline Mountain Palynoflora

Slide No. 39: 96SR 001(1)

1. cf. *Alisporites bilateralis* Rouse 1959: R1-10a, ↑, 4E-F

Slide No. 40: 96SR 002(2)

2. *Abietieneaepollenites* sp.: R2-14a, ↑, 12P

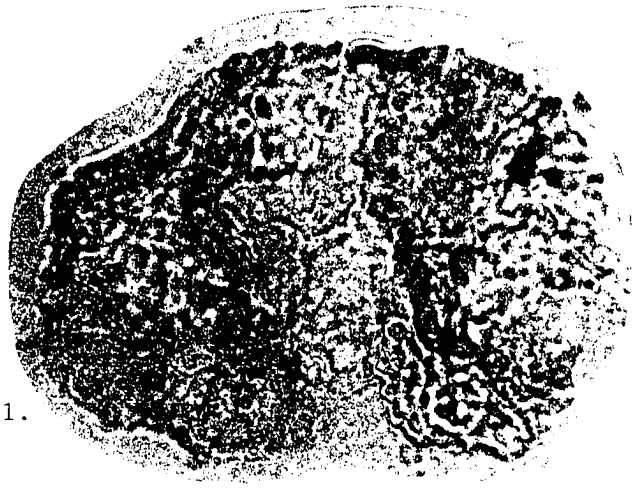
Slide No. 39: 96SR 001(2)

3. cf. *Cedripites sp.*: R2-26a, ↑, 16T

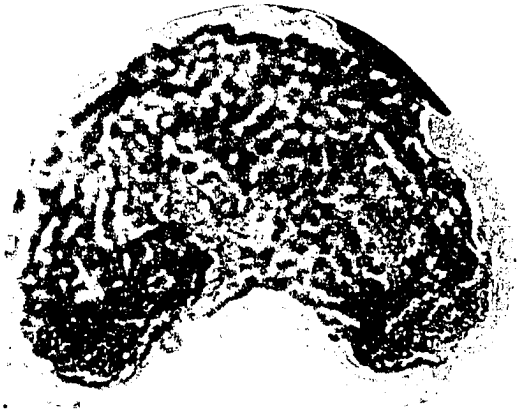
4. *Pityosporites constrictus* Singh 1964: R2-27a, ↑, 15P

5. cf. *Rugubivesiculites* sp.: R2-31a, ↑, 6H

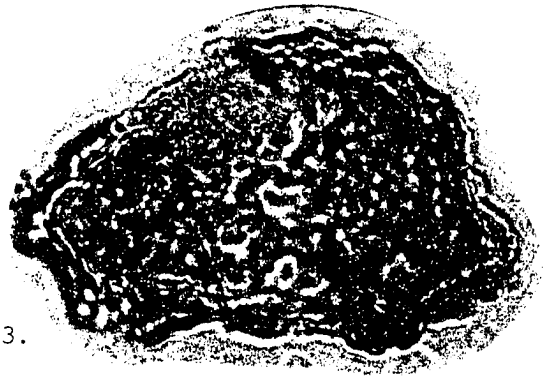
Plate 168



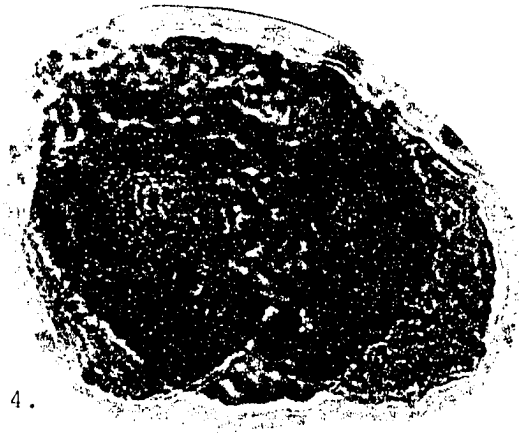
1.



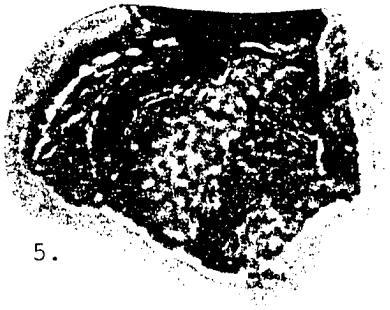
2.



3.



4.



5.

25 µm

Plate 169

Syncline Mountain Palynoflora

Slide No. 40: 96SR 002(2)
1. *Liliacidites inaequalis* Singh 1971: R2-15a, ↑, 12P

Slide No. 40: 96SR 002(1)
2. Triporate sp.: R2-18a, ↓, 29U

3. *Quercoidites sternbergi* Srivastava 1967: R2-20a, ↑, 4N

4. *Extratriporopollenites* sp.: R2-24a, ↑, 16M

Slide No. 39: 96SR 001(2)
5. *Proteacidites auratus* Srivastiva 1969: R2-29a, ↑, 8J

Slide No. 40: 96SR 002(2)
6. *Cranwellia striata* (Couper) Srivastava 1966: R2-13a, ↑, 12P

Slide No. 40: 96SR 002(1)
7. *C. striata*: R2-16a, ↓, 7T

Plate 169

Plate 170

Syncline Mountain Palynoflora

Slide No. 39: 96SR 001(1)

1. *Aquilapollenites notabile* (Mchedlishvili) Farabee 1990: R1-6a, ↑, 14P

2. *Aquilapollenites senonicus* (Mtchedlishvili) Tschudy and Leopold 1969: R1-3a, ↑, 5G-H

Slide No. 40: 96SR 002(1)

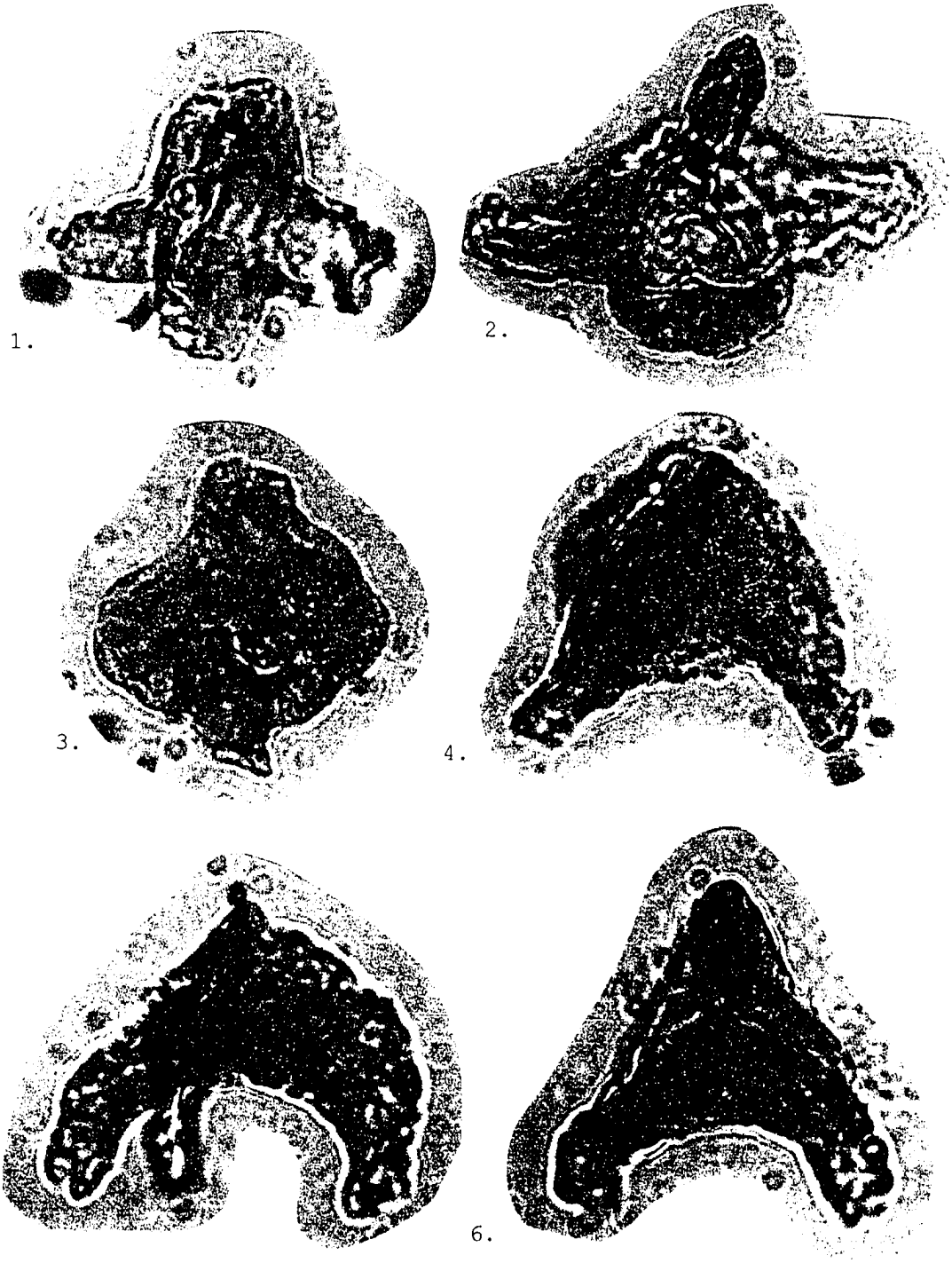
3. *Aquilapollenites spinulosus* Funkhouser 1961: R2-23a, ↑, 7Q

4. *Mancicorpus albertensis* Srivastava 1970: R2-22a, ↑, 6R

5. *Mancicorpus* sp. cf. *M. tripodiformis* (Tschudy and Leopold) Tschudy 1973: R2-25a, ↑, 19T

6. *Mancicorpus rostratus* Srivastava 1968: R2-19a, ↑, 6N

Plate 170



APPENDIX H
Photographic Plates

Hicks Creek Palynomorphs

	WOOD CELLS
1	Unidentified Wood

	Spores	
	Genus	**Species**
1	*Concavissimisporites*	*punctatus*
2	*Deltoidospora*	sp.
3	*Gleicheniidites*	*circinidites*
4	*Gleicheniidites*	cf. *circinidites*
5	*Laevigatosporites*	sp.
6	cf. *Microreticulatisporites*	sp.
7	*Monosulcites*	sp.
8	*Neoraistrickia*	*truncata*
9	*Ornamentifera*	*baculata*
10	cf. *Retitriletes*	*subreticulaesporites*
11	*Undulatisporites*	*fossulatus*
12	Unidentified	sp.

	Pollen	
	Genus	**Species**
1	*Abietineaepollenites*	*varius*
2	*Alisporites*	*bilateralis*
3	*A.*	*grandis*
4	*A.*	cf. *microsaccus*
5	*Cedripites*	*canadensis*
6	*Cycadopites*	sp.
7	*Pityosporites*	sp.
8	*Podocarpidites*	*biformis*
9	*P.*	*canadensis*
10	*P.*	*minisculus*
11	*P.*	*multesimus*
12	*P.*	*granulatus*
13	*Tricolpate*	sp.
14	*Triprojectate*	sp.
15	*Vitreisporites*	*pallidus*
16	cf. *V.*	*pallidus*

Plate 171

Hicks Creek Palynoflora

Slide No. 96SR HCK 002(1)
1. Wood: R34-15, ↑, 3L

2. Wood: R34-1, ↑, 15H

Plate 171

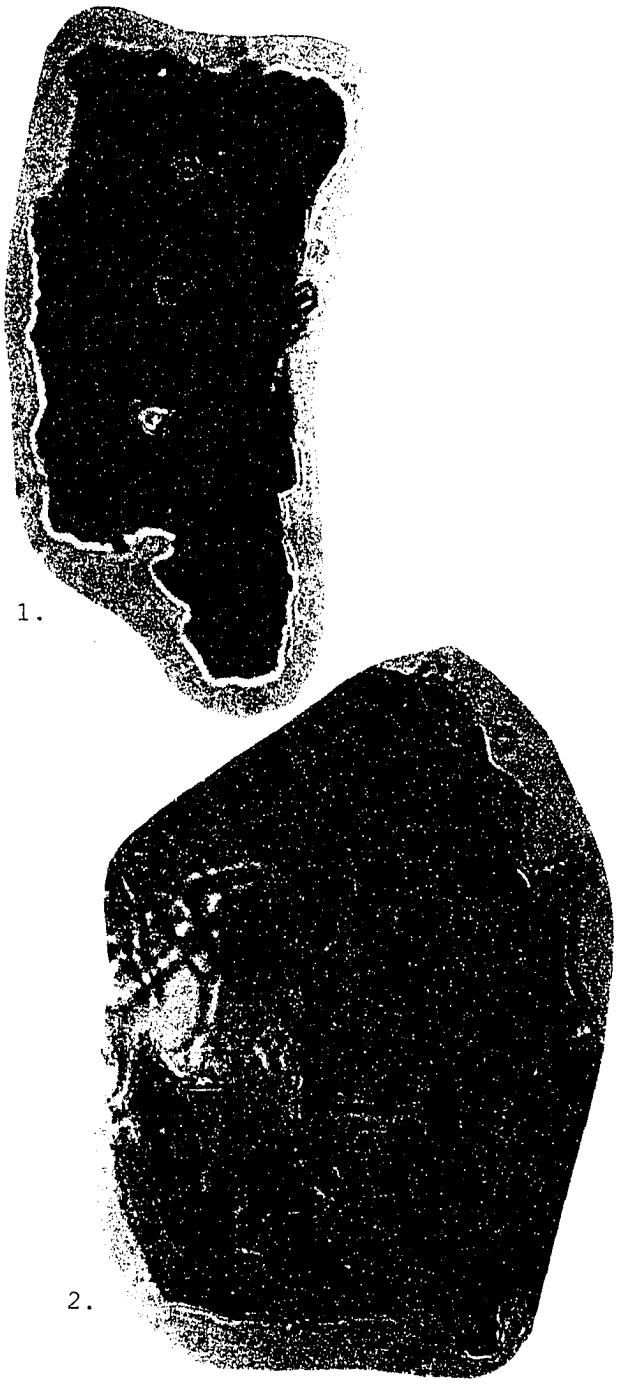


Plate 172

Hicks Creek Palynoflora

Slide No. 96SR HCK 001(2)

1. *Laevigatosporites* sp.: R34-6, ↑, 12R

Slide No. 96SR HCK 002(1)

2. *Deltoidospora* sp.: R34-13, ↓, 32W

3. *Undulatisporites fossulatus* Singh 1971: R34-12, ↓, 33V-W

Slide No. 96SR HCK 002(2)

4. *Gleicheniidites* sp. cf. *G. circinidites* (Cookson) Brenner 1963: R34-19, ↑, 13G

Slide No. 96SR HCK 002(1)

5. *Gleicheniidites circinidites* (Cookson) Brenner 1963: R34-11, ↓, 36N

Slide No. 96SR HCK 001(1)

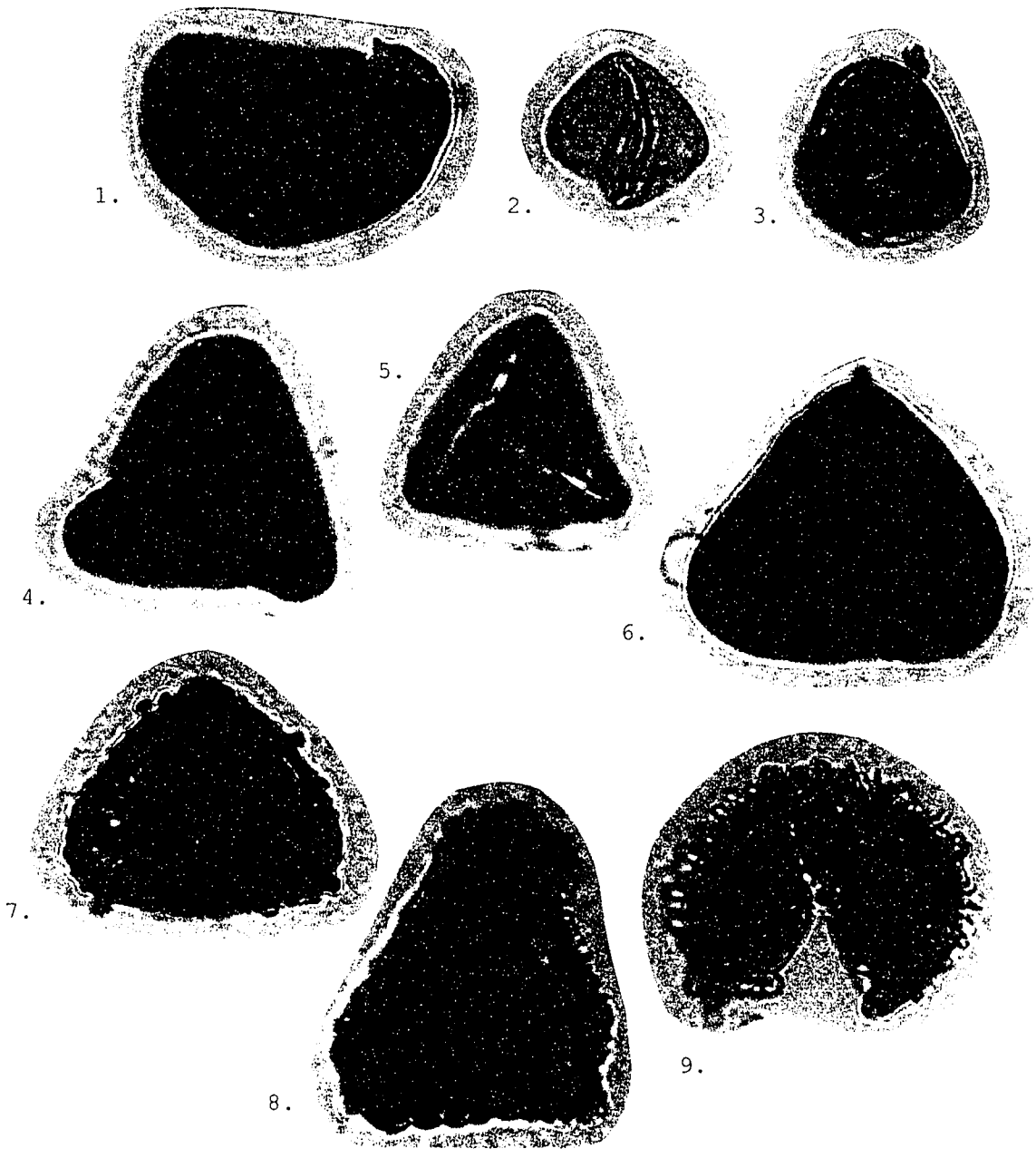
6. *Concavissimisporites punctatus* (Delcourt and Sprumont) Brenner 1963: R34-9, ↓, 7N

7. *Ornamentifera baculata* Singh 1971: R34-10, ↓, 2M

8. *O. baculata*: R34-7, ↓, 9G-H

9. *Neoraistrickia truncata* (Cookson) Potonié 1956: R34-8, ↓, 7J-K

Plate 172



25 μm

Plate 173

Hicks Creek Palynoflora

Slide No. 96SR HCK 001(2)

1. cf. *Retitriletes subreticulaesporites* (Rouse) Krutzsch 1963: R34-5, ↑, 9-10Q

2. Unknown genus: R34-4, ↑, 7N

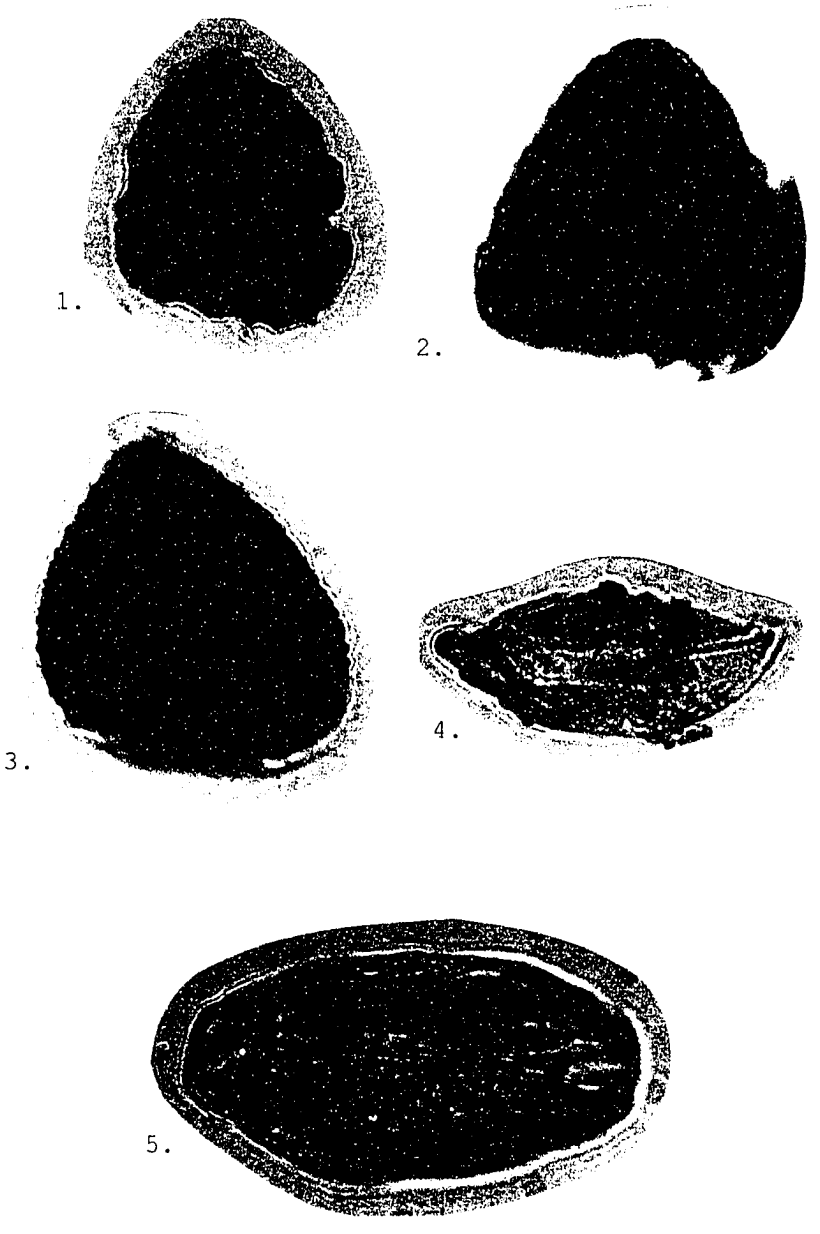
3. cf. *Microreticulatisporites* sp.: R34-3, ↑, 6N

4. *Monosulcites* sp.: R34-16, ↑, 9J

Slide No. 96SR HCK 002(2)

5. *Cycadopites reticulatus* (Nilsson) Cornet and Traverse 1975: R34-23, ↑, 18-19Q

Plate 173



25 μm

Plate 174

Hicks Creek Palynoflora

Slide No. 96SR HCK 001(1)

1. *Vitreisporites pallidus* (Reissinger) Nilsson 1958: R2-6a, ↑, 23J

Slide No. 38: 96SR HCK 002(1)

2. cf. *V. pallidus* (Reissinger) Nilsson 1958: R3-25a, ↓, 34N

3. *Pityosporites* sp.: R3-24a, ↓, 35P

4. *Pityosporites* sp.: R3-23a, ↓, 34Q

Slide No. 38: 96SR HCK 002(1)

5. *Abietineaepollenites varius* Norton in Norton and Hall 1969: R3-29a, ↑, 18E

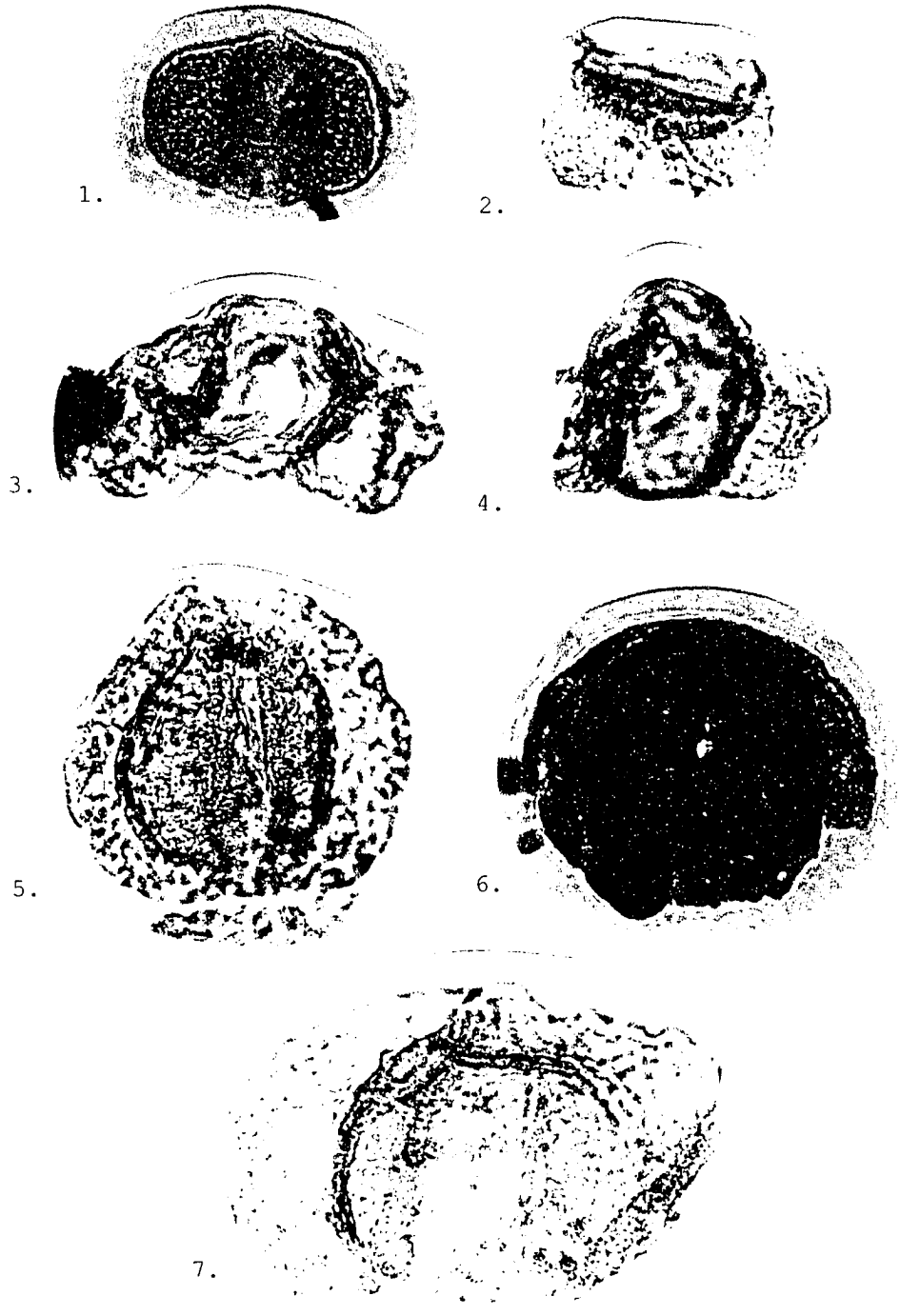
Slide No. 37: 96SR HCK 001(1)

6. *Alisporites* sp. cf. *A. microsaccus* (Couper) Pocock 1962: R2-11a, ↑, 14N

Slide No. 38: 96SR HCK 002(1)

7. *Alisporites grandis* (Cookson) Dettmann 1963: R3-28a, ↑, 12X

Plate 174



25 μm

Plate 175

Hicks Creek Palynoflora

Slide No. 96SR HCK 001(1)

1. *Podocarpidites granulatus* Singh 1971: R3-31a, ↓, 36K

2. *P. granulatus*: R2-0a, ↓, 2G

Slide No. 96SR HCK 001(1)

3. *Podocarpidites multesimus* (Bolkhovitina) Pocock 1962: R2-1a, ↓, 32V

Slide No. 96SR HCK 001(2)

4. *Podocarpidites biformis* Rouse 1957: R3-30a, ↑, 9G

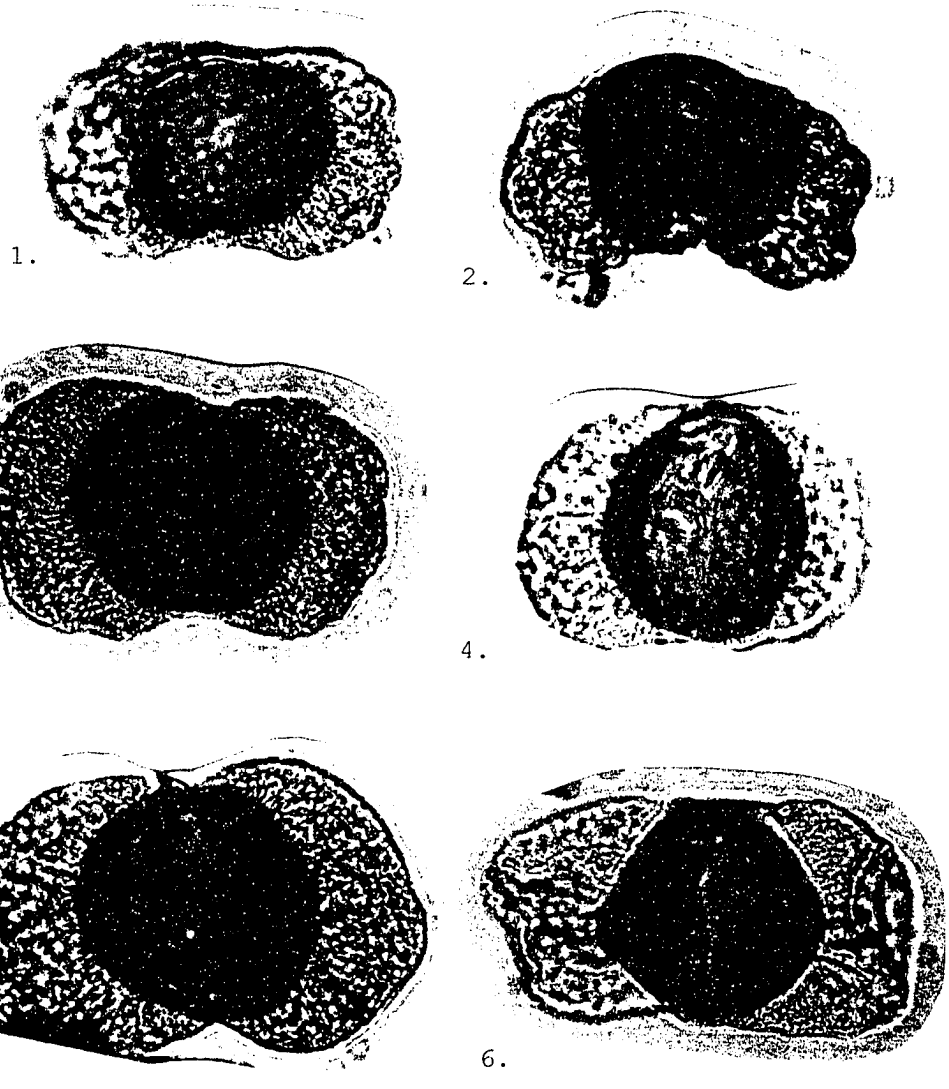
Slide No. 96SR HCK 001(1)

5. *Podocarpidites canadensis* (Pocock) Singh 1971: R2-12a, ↑, 13G

Slide No. 96SR HCK 002(2)

6. *P. biformis*: R34-20, ↑, 13V

Plate 175



25 µm

Plate 176

Hicks Creek Palynoflora

Slide No. 96SR HCK 002(2)

1. *Cedripites canadensis* Pocock 1962: R34-17, ↑, 10T

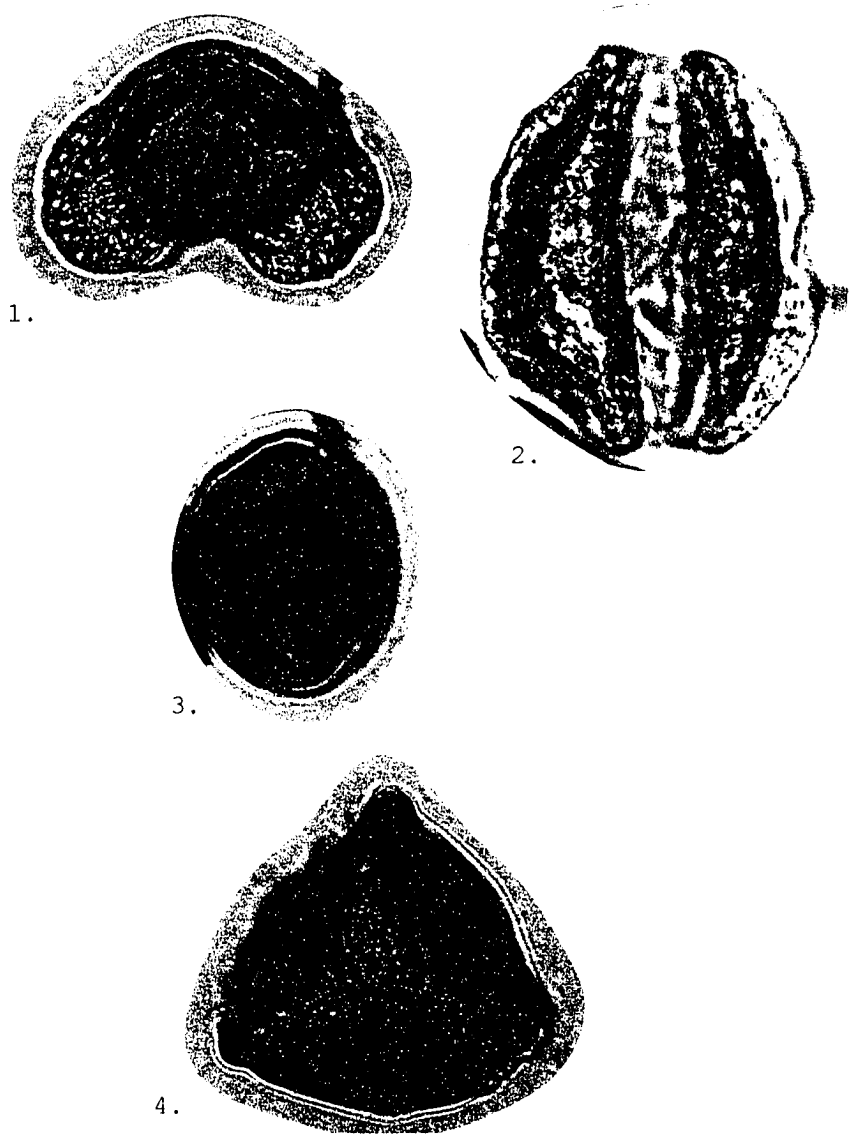
2. *Podocarpidites minisculus* Singh 1964: R34-18, ↑, 11V

3. Tricolpate sp.: R34-22, ↑, 17S-T

Slide No. 96SR HCK 002(1)

4. Triprojectate sp.: R34-14, ↑, 16F

Plate 176



25 µm

APPENDIX I
Photographic Plates

Slide Mountain Palynomorphs

	WOOD CELLS
1	cf. *Sequoia*
2	Unidentified Wood

	SPORES	
	Genus	**Species**
1	*Aequitriradites*	*spinulosus*
2	*Ceratosporites*	cf. *couliensis*
3	*Cibotiumspora*	*juncta*
4	*Cicatricosisporites*	sp.
5	*C.*	sp.
6	*Concavissimisporites*	sp.
7	*Contignisporites*	sp.
8	*Deltoidospora*	*diaphana*
9	*D.*	*hallii*
10	*D.*	sp.
11	cf. D.	*psilostoma*
12	*Dictyophyllidites*	*harrisii*
13	*D.*	*mortonii*
14	*D.*	sp.
15	*Distaltriangulisporites*	*maximus*
16	*D.*	*perplexus*
17	*Gleicheniidites*	*circinidites*
18	*G.*	*umbonatus*
19	*G.*	sp.
20	*Hamulatisporis*	*amplus*
21	*Hazaria*	*sheoparii*
22	*Laevigatosporites*	sp.
23	*Leptolepidites*	*crepitus*
24	*L.*	*proxigranulatus*
25	*L.*	*verrucatus*
26	*Microfoveolatisporis*	*pseudoreticulatus*
27	*Neoraistrickia*	*truncata*
28	*N.*	sp.
29	*Ornamentifera*	*echinata*
30	*Polycingulatisporites*	*reduncus*

	SPORES	
	Genus	**Species**
31	*Retitriletes*	*austroclavatidites*
32	*R.*	*subreticulaesporites*
33	*Sestrosporites*	*pseudoalveolatus*
34	*Todisporites*	sp.
35	*Triancoraeosporites*	*reticulatus*
36	*Umbosporites*	*callosus*
37	Unidentified	spp.

	POLLEN	
	Genus	**Species**
1	*Abiespollenites*	spp.
4	*Alnipollenites*	*verus*
5	*Aquilapollenites*	*conatus*
6	*A.*	*delicatus* var. *delicatus*
7	*A*	*polaris*
8	*A.*	*spinulosus*
9	*A.*	*trialatus*
10	*A.*	cf. *reticulatus*
11	*Beaupreadites*	*elegansiformis*
12	*B.*	sp.
13	*Callistopollenites*	*radiostriatus*
14	*Cedripites*	*cretaceus*
15	*C.*	*parvus*
16	*C.*	sp.
17	*Cupanieidites*	*major*
18	*Cycadopites*	*reticulatus*
19	*Ephedrapites*	spp.
21	*Eucommiidites*	*troedssonii*
22	*cf. Expressipollis*	*ocliferus*
23	*Extratriporopollenites*	sp.
24	*Fraxinoipollenites*	*constrictus*
25	*F.*	sp.
26	*Nyssapollenites*	*albertensis*
27	*Oculopollis*	*orbicularis*
28	*O.*	sp.
29	*Pinuspollenites*	spp.
31	*Pityosporites*	*elongatus* var. *elongatus*
32	*Podocarpidites*	*epistratus*

	POLLEN	
	Genus	**Species**
33	*P.*	*minisculus*
34	*P.*	*multesimus*
35	*Proteacidites*	*retusus*
36	*P.*	*thalmanni*
37	*P.*	spp.
40	*Retibrevitrocolporites*	*beccus*
41	*Rugubivesiculites*	*reductus*
42	*R.*	sp.
43	*Sequoiapollenites*	*papillapollenites*
44	*Taxodiaceaepollenites*	*hiatus*
45	*Triporopollenites*	cf. *mullensis*
46	*Trudopollis*	*hemiperfectus*
47	*Vitreisporites*	*pallidus*

Plate 177

Slide Mountain Paleoflora

Slide No. 94SR SM07(1)
1. Wood: R33-32, ↓, 16M

2. Wood: R33-12, ↓, 38S

3. Wood: R33-21, ↓, 31T

4. Wood: R33-33, ↓, 23M

Slide No. 94SR SM07(2)
5. Wood: R32-10, ↑, 13K

Slide No. 94SR SM07(1)
6. Wood: R32-23, ↑, 9-10F

7. cf. *Sequoia* Tidwell 1998: R33-22, ↓, 30Q-R

Plate 177

Plate 178

Slide Mountain Paleoflora

Slide No. 94SR SM06(2)
1. Wood: R33-8, ↑, 16M

Slide No. 94SR SM07(1)
2. Wood: R33-17, ↓, 31-32P

3. Wood: R33-29, ↓, 25J-K

Slide No. 94SR SM06(1)
4. Wood: R33-4, ↓, 27H

Slide No. 94SR SM07(1)
5. Wood: R32-25, ↑, 10N-P

6. Wood: R32-35, ↑, 17Q

Plate 178

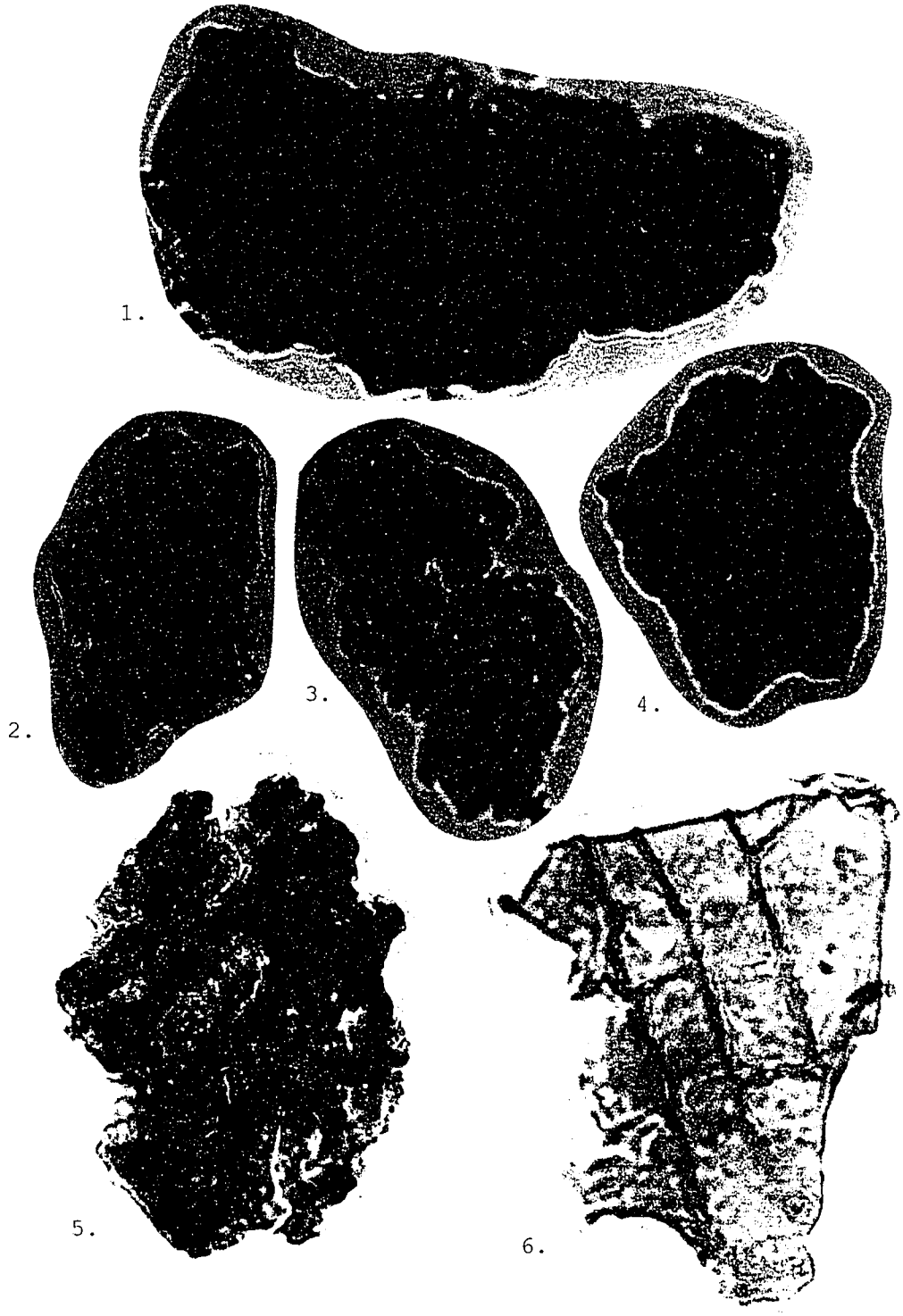


Plate 179

Slide Mountain Paleoflora

Slide No. 94SR SM04(1)
1. *Laevigatosporites* sp.: R31-37, ↓, 27P-N

Slide No. 94SR SM07(2)
2. *Hazaria sheoparii* Srivastava 1971: R32-4, ↑, 6-7L

Slide No. 94SR SM06(1)
3. *Microfoveolatisporis pseudoreticulatus* (Hedlund) Singh 1983: R33-1, ↓, 30S

Slide No. 94SR SM07(2)
4. *Umbosporites callosus* Newman 1965: R32-6, ↑, 9F-G

Slide No. 94SR SM07(1)
5. *Aequitriradites spinulosus* (Cookson and Dettmann) Cookson and Dettmann 1961: R32-20, ↑, 7P

6. *Neoraistrickia* sp.: R33-26, ↓, 26S-T

7. *Contignisporites* sp.: R32-22, ↑, 9J-K

8. *Cicatricosisporites* sp.: R33-15, ↓, 34L

9. *Cicatricosisporites* sp.: R31-1, ↑, 7-8G

Plate 179

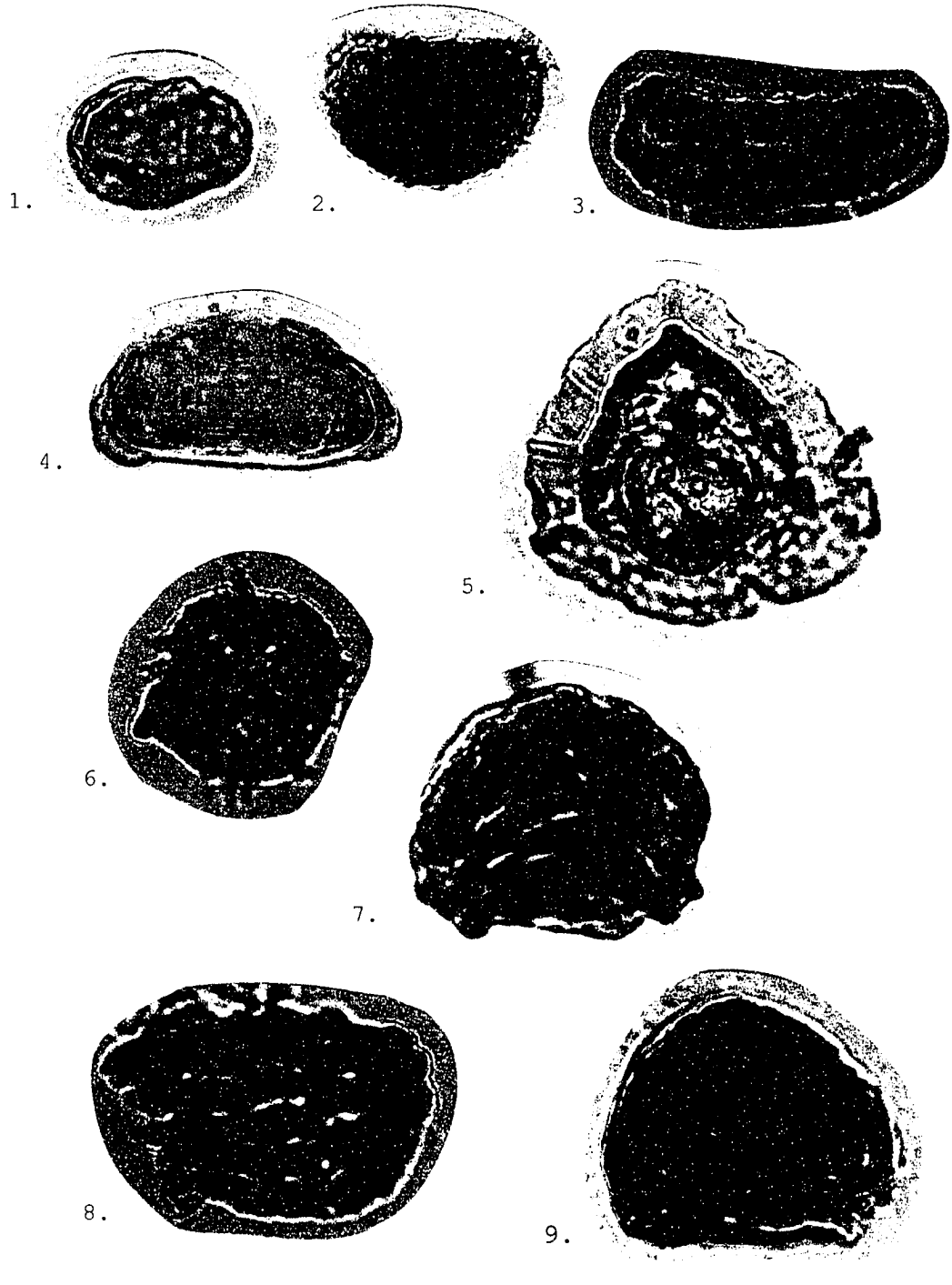


Plate 180

Slide Mountain Paleoflora

Slide No. 94SR SM04(1)

1. *Ornamentifera echinata* (Bolkhovitina) Bolkhovitina 1966: R31-26, ↓, 31-32W

2. Unknown genus: R31-25, ↓, 31F

Slide No. 94SR SM07(1)

3. *Retitriletes austroclavatidites* (Cookson) Krutzsch 1963: R31-7, ↑, 7L

Slide No. 94SR SM06(1)

4. *Deltoidospora* diaphana Wilson and Webster 1946: R31-16, ↓, 35M

Slide No. 94SR SM04(1)

5. *Deltoidospora hallii* Miner 1935: R31-32, ↓, 35K

6. *Dictyophyllidites harrisii* Couper 1958: R31-30, ↓, 34T-U

Slide No. 94SR SM06(1)

7. Unknown genus: R31-17, ↓, 40H

Slide No. 94SR SM04(1)

8. Unknown genus: R31-31, ↓, 25Q

Slide No. 94SR SM07(1)

9. *Todisporites* sp.: R31-3, ↑, 13P-Q

Plate 180

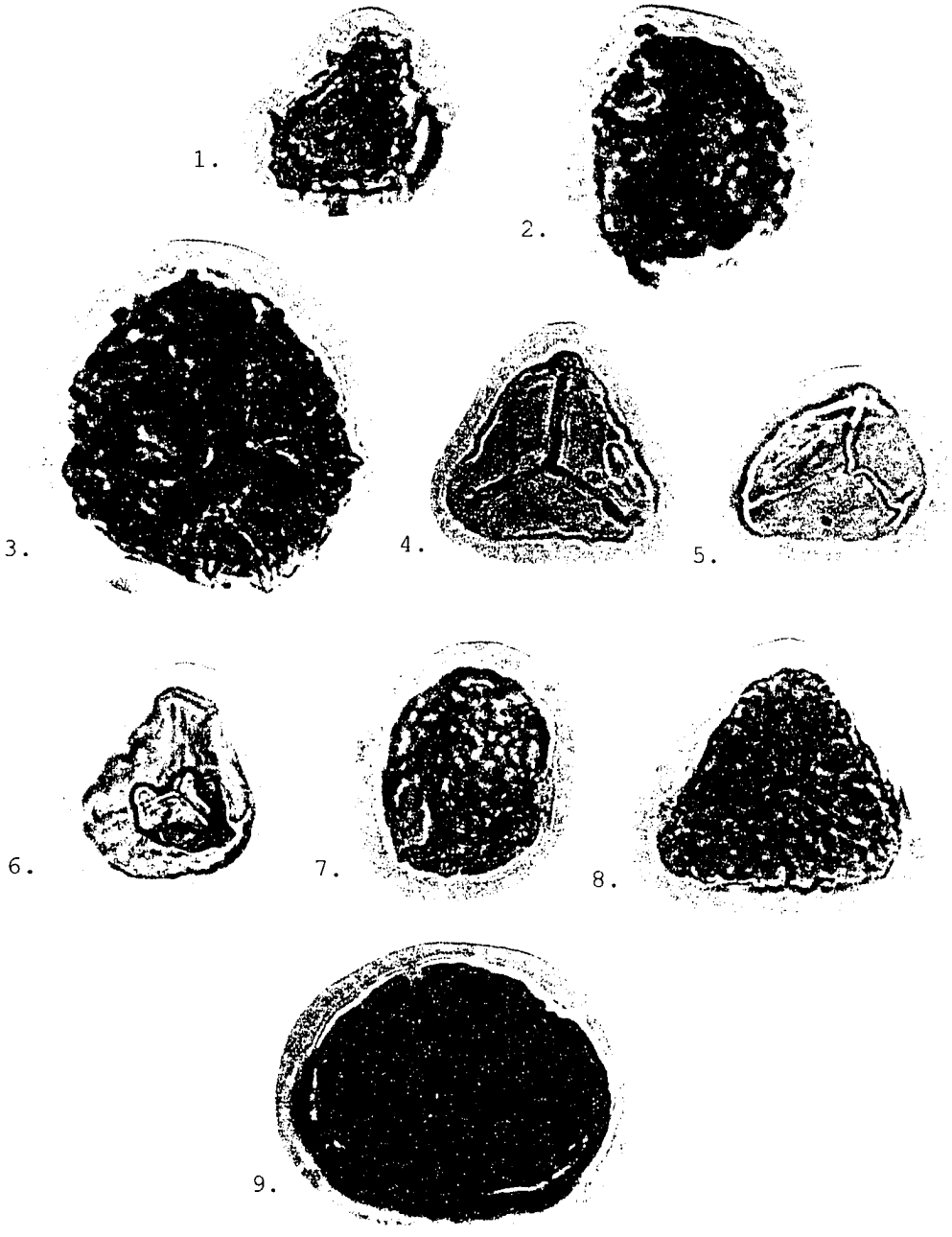


Plate 181

Slide Mountain Paleoflora

Slide No. 94SR SM07(2)

1. cf. *Deltoidospora psilostoma* Rouse 1959: R32-7, ↑, 11K

Slide No. 94SR SM07(1)

2. *Polycingulatisporites reduncus* (Bokhovitina) Playford and Dettmann, 1965: R33-24, ↓, 28R-S

3. *Retitriletes subreticulaesporites* (Rouse) Krutzsch 1963: R33-31, ↓, 25N-P

Slide No. 94SR SM07(2)

4. *Sestrosporites pseudoalveolatus* (Couper) Dettmann 1963: R32-8, ↑, 12S-T

Slide No. 94SR SM07(1)

5. *Trianchoraeosporites reticulatus* Schulz 1962: R33-25, ↓, 26-27Q

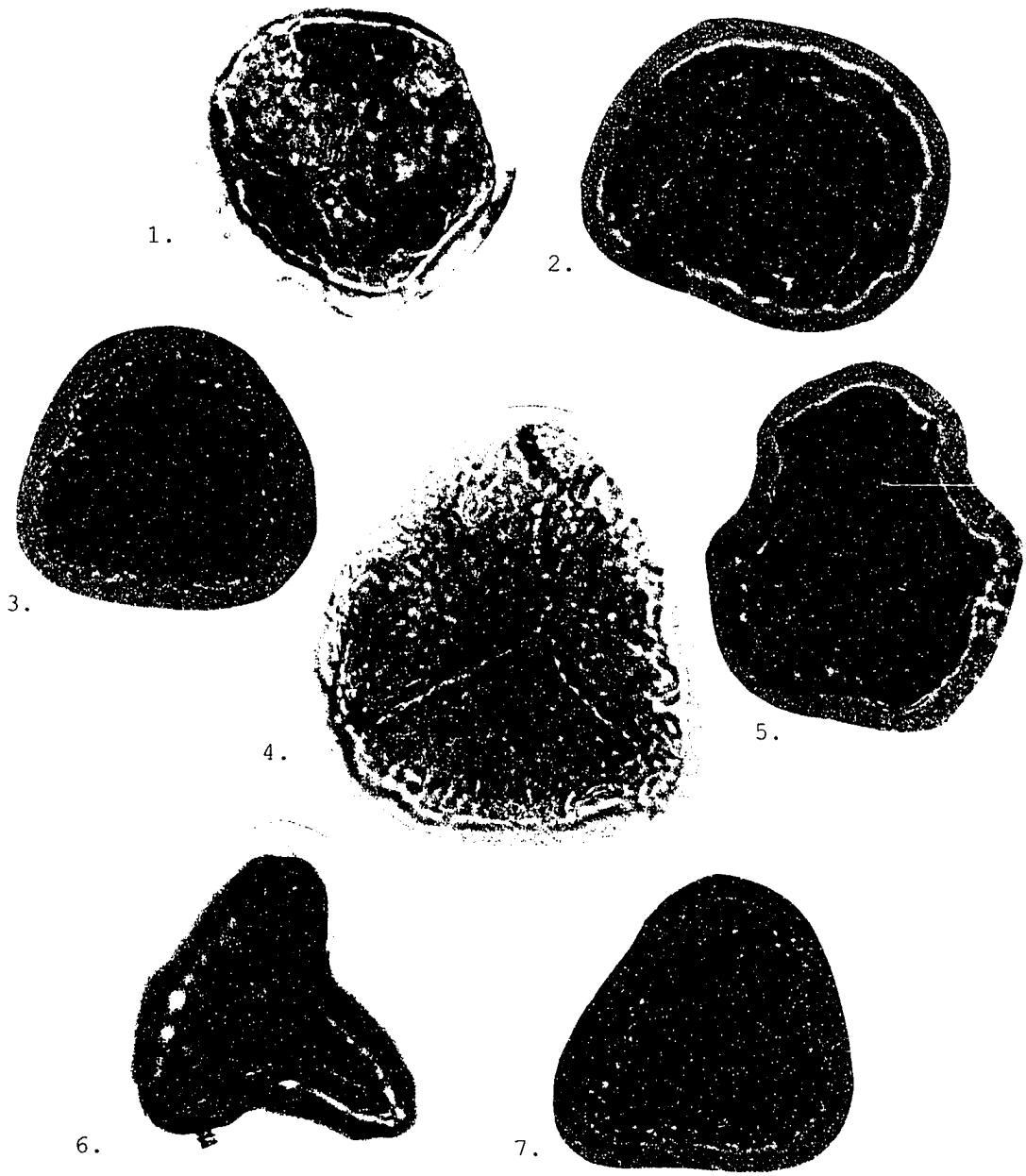
Slide No. 94SR SM07(2)

6. *Gleicheniidites umbonatus* (Bolkhovitina) Bolkhovitina 1968: R32-9, ↑, 13H-J

Slide No. 94SR SM07(1)

7. *Neoraistrickia truncata* (Cookson) Potonié 1956: R33-34/35, ↓, 23-24W

Plate 181



25 µm

Plate 182

Slide Mountain Paleoflora

Slide No. 94SR SM04(2)

1. *Cibotiumspora juncta* (Kara-Murza) Singh 1989: R31-20, ↑, 7K

Slide No. 94SR SM06(1)

2. *Gleicheniidites circinidites* (Cookson) Brenner 1963: R31-15, ↓, 28-29M

Slide No. 94SR SM07(1)

3. *Dictyophyllidites mortonii* (de Jersey) Playford and Dettman 1965: R31-4, ↑, 14U

Slide No. 94SR SM06(1)

4. *Leptolepidites proxigranulatus* (Brenner) Dorhofer 1979: R31-12, ↓, 33L

Slide No. 94SR SM06(2)

5. *Leptolepidites crepitus* Singh 1971: R31-9, ↑, 18K

Slide No. 94SR SM04(1)

6. *Ceratosporites* sp. cf. *C. couliensis* Srivastava 1972: R31-22, ↓, 6F

7. *Leptolepidites verrucatus* Couper 1953: R31-21, ↓, 23J

Plate 182

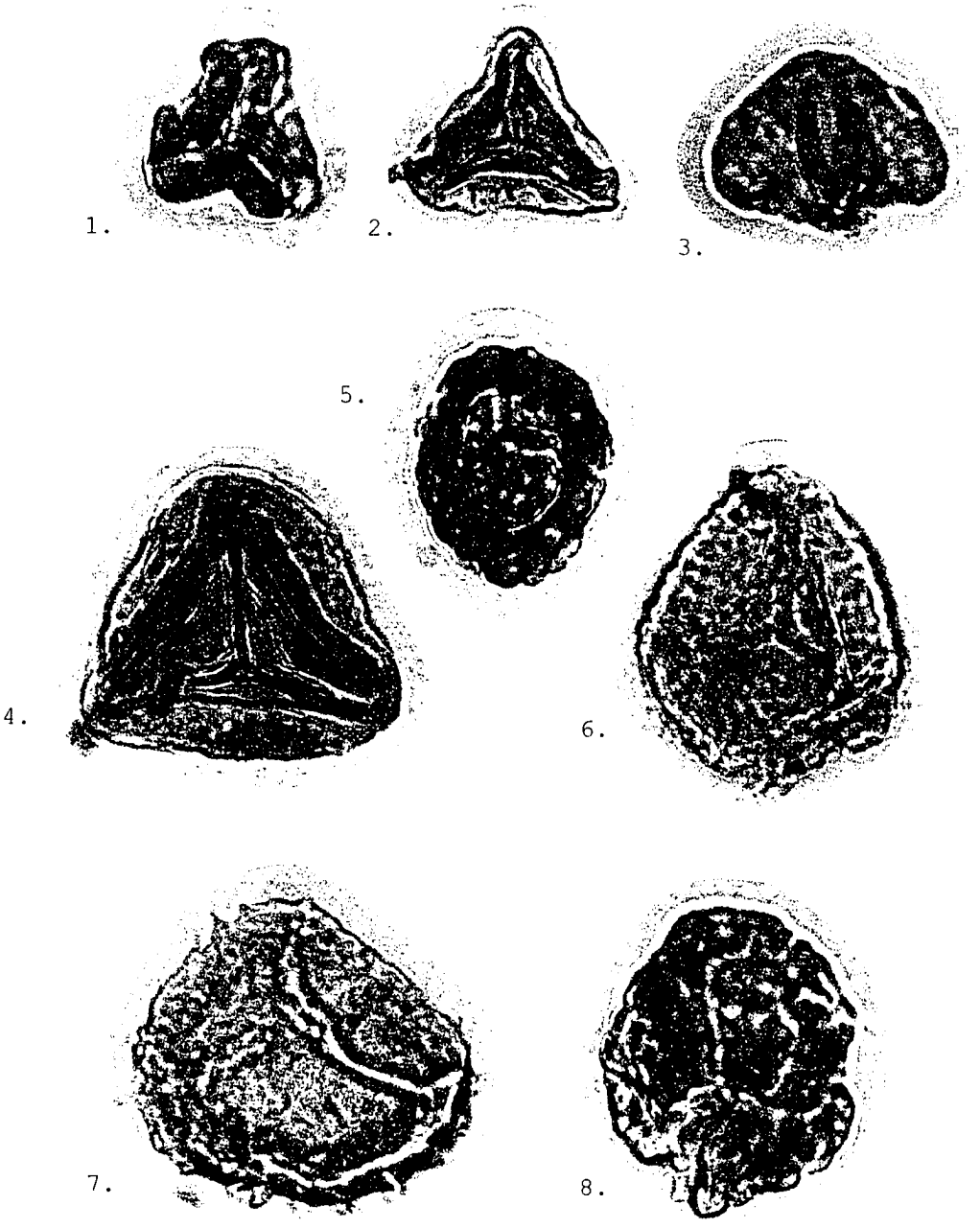


Plate 183

Slide Mountain Paleomorphs

Slide No. 94SR SM06(2)
1. Unknown genus: R31-10, ↑, 14P

Slide No. 94SR SM06(1)
2. Unknown genus: R31-19, ↑, 12E

Slide No. 94SR SM07(1)
3. *Deltoidospora* sp.: R31-5, ↑, 18-19J

Slide No. 94SR SM06(2)
4. *Gleicheniidites* sp.: R31-8, ↑, 6M

Slide No. 94SR SM04(1)
5. *Dictyophyllidites* sp.: R31-29, ↑, 17-18M

6. *Distaltriangulisporites maximus* Singh 1971: R31-23, ↑, 13K

Slide No. 94SR SM07(1)
7. *Distaltriangulisporites perplexus* (Singh) Singh 1971: R32-21, ↑, 8R

Plate 183

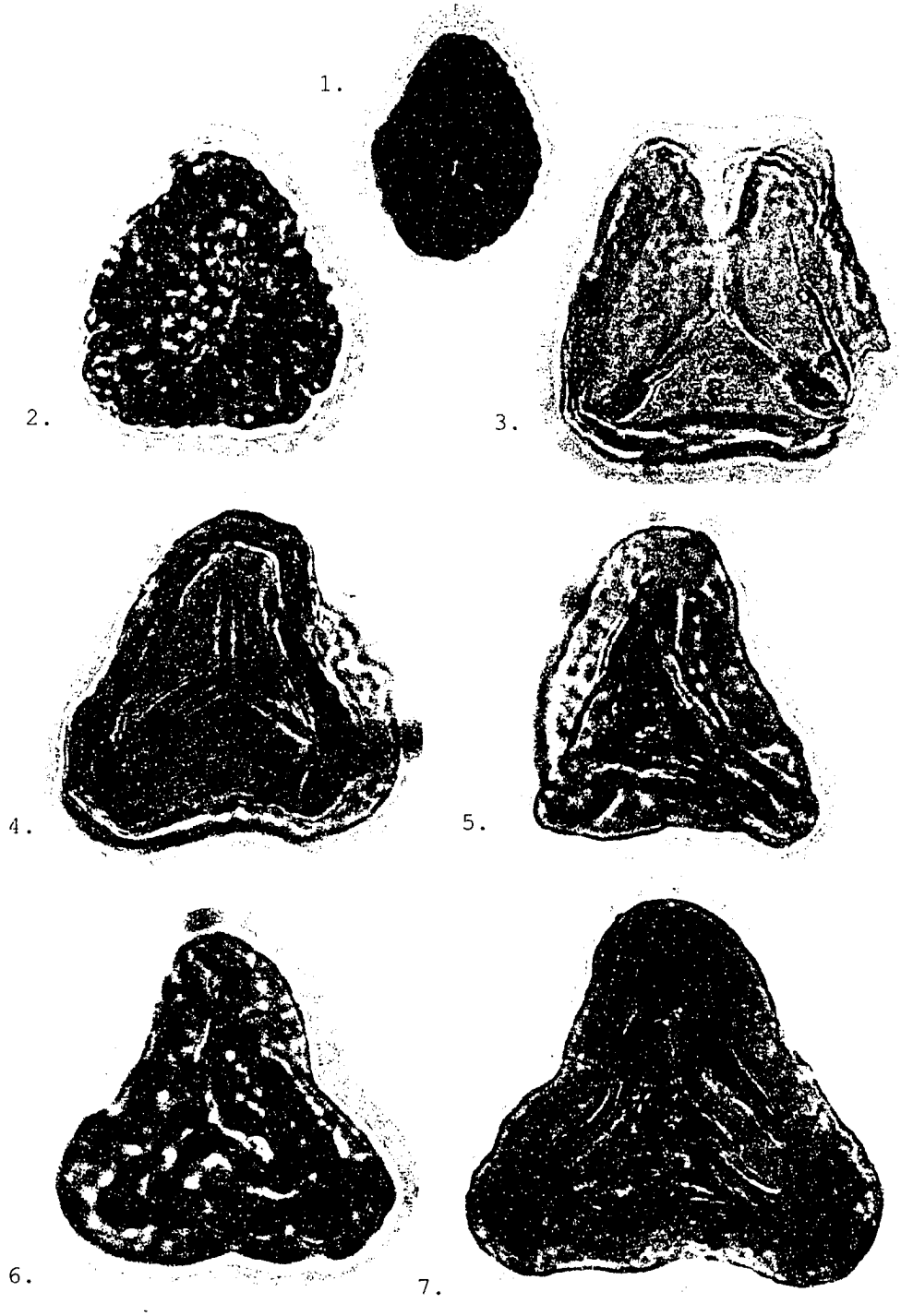


Plate 184

Slide Mountain Paleoflora

Slide No. 94SR SM07(1)

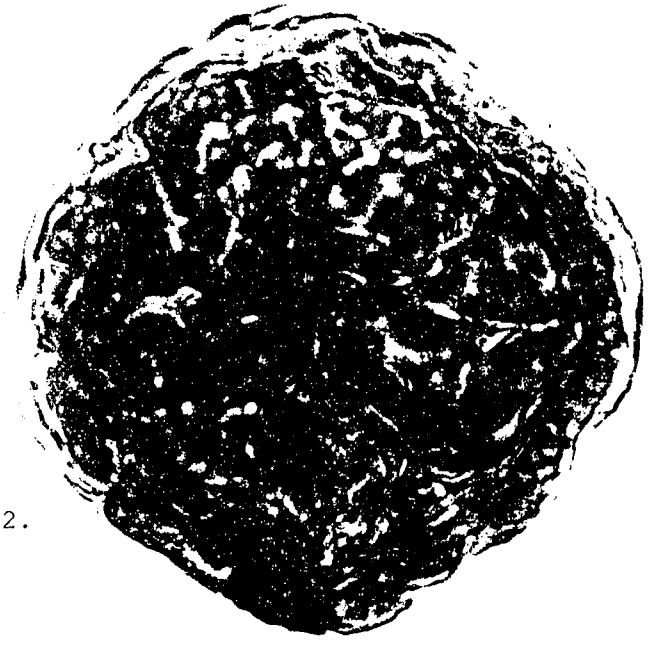
1. *Concavissimisporites* sp.: R31-2, ↑, 10U-V

2. *Hamulatisporis amplus* Stanley 1965: R32-34, ↑, 15Q-R

Plate 184

1.

2.



25 μm

Plate 185

Slide Mountain Paleoflora

Slide No. 94SR SM07(1)
1. *Vitreisporites pallidus* (Reissinger) Nilsson 1958: R4-17a, ↓, 27P

Slide No. 94SR SM06(2)
2. *Taxodiaceaepollenites hiatus* (Potonié) Kremp 1949: R4-28a, ↑, 16- 17L

Slide No. 94SR SM07(1)
3. *Sequoiapollenites papillapollenites* (Rouse) Srivastiva 1969: R4-15a, ↓, 33G

Slide No. 94SR SM06(1)
4. *Podocarpidites minisculus* Singh 1964: R3-4a, ↑, 11P

Slide No.94SR SM07(1)
5. *Podocarpidites multesimus* (Bolkhovitina) Pocock 1962: R32-15, ↑, 12F

Slide No. 94SR SM06(1)
6. *Podocarpidites epistratus* Brenner 1963: R34-37, ↓, 30M-N

7. *Cedripites* sp.: R3-5a, ↑, 14H

Slide No. 94SR SM07(1)
8. *Cedripites cretaceus* Pocock 1962: R32-26, ↑, 11T-U

9. *Cedripites parvus* Norton *in* Norton and Hall 1969: R32-30, ↑, 14-15G

Plate 185

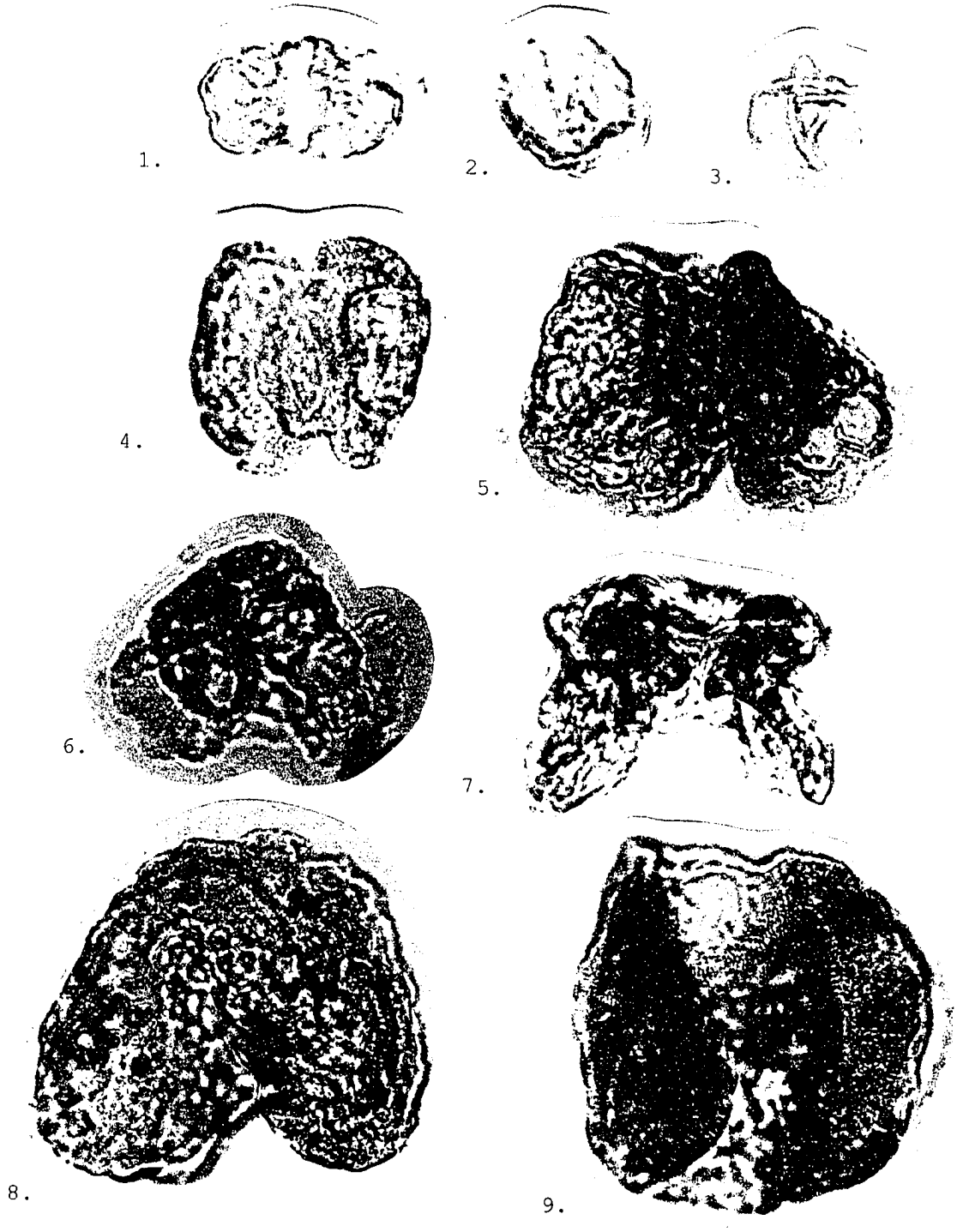


Plate 186

Slide Mountain Paleoflora

Slide No. 94SR SM07(1)
1. *Abiespollenites* sp.: R4-7a, ↑, 11S

Slide No. 94SR SM06(1)
2. *Abiespollenites* sp.: R33-3, ↓, 28S

Slide No. 94SR SM07(2)
3. *Pinuspollenites* sp.: R33-10, ↑, 13K

Slide No. 94SR SM07(1)
4. *Pinuspollenites* sp.: R32-31,

5. *Rugubivesiculites reductus* Pierce 1961: R4-10a, ↑, 18Q

6. *Podocarpidites epistratus* Brenner 1963: R33-14, ↓, 33-34M

Slide No. 94SR SM04(1)
8. *Pityosporites elongatus* (Norton) var. *elongatus* Tschudy 1973: R3-20a, ↑, 18T

Plate 186

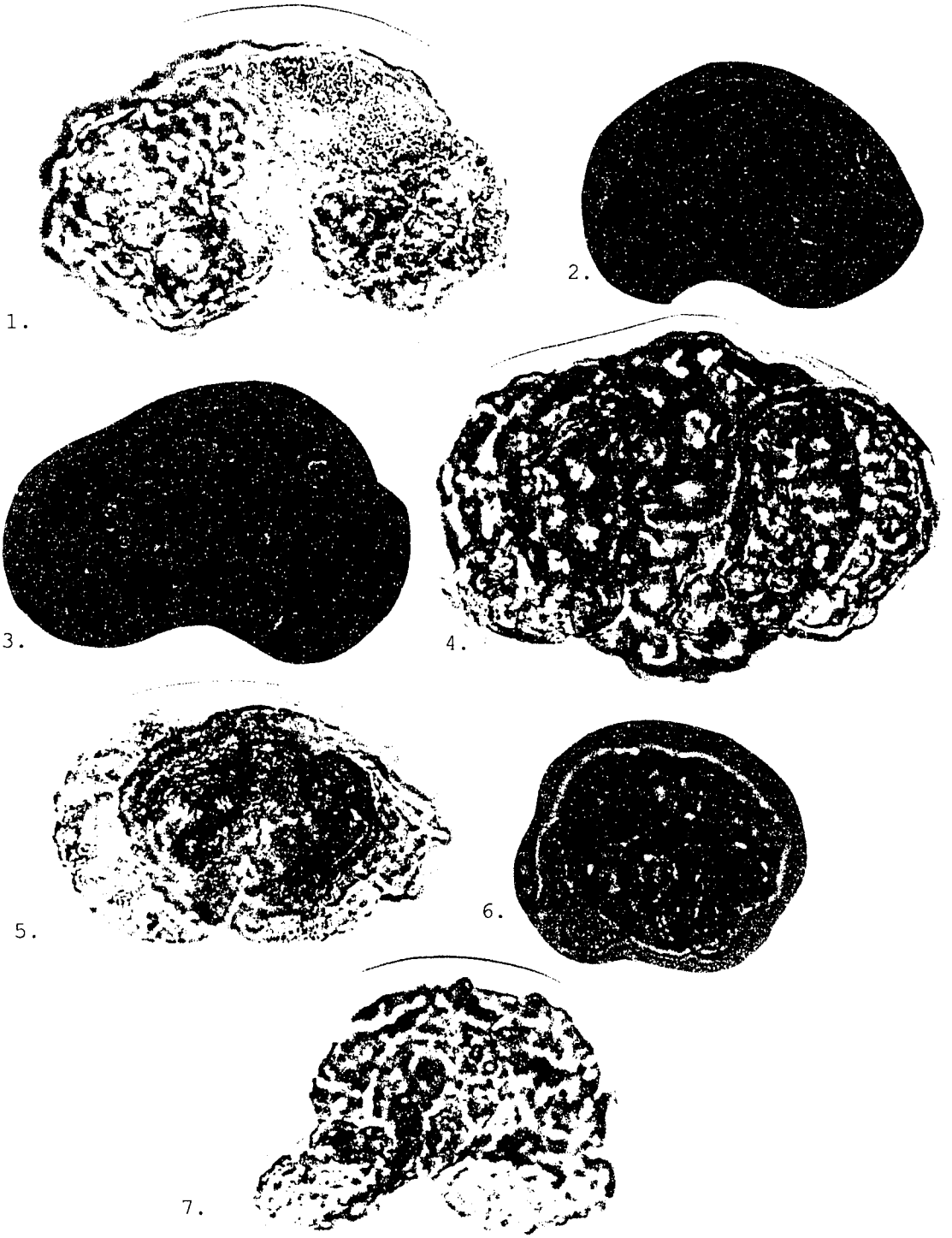


Plate 187

Slide Mountain Paleoflora

Slide No. 94SR SM07(1)
1. *Rugubivesiculites* sp.: R4-8a, ↑, 16Q

Slide No. 94SR SM04(1)
2. *Pinuspollenites* sp.: R3-19a, ↓, 29U

Slide No. 94SR SM07(1)
3. *Cedripites cretaceus* Pocock 1962: R4-9a, ↑, 18R

4. *Abiespollenites* sp. (*sensu* Singh 1971): R4-11a, ↓, 4G-H

Plate 187

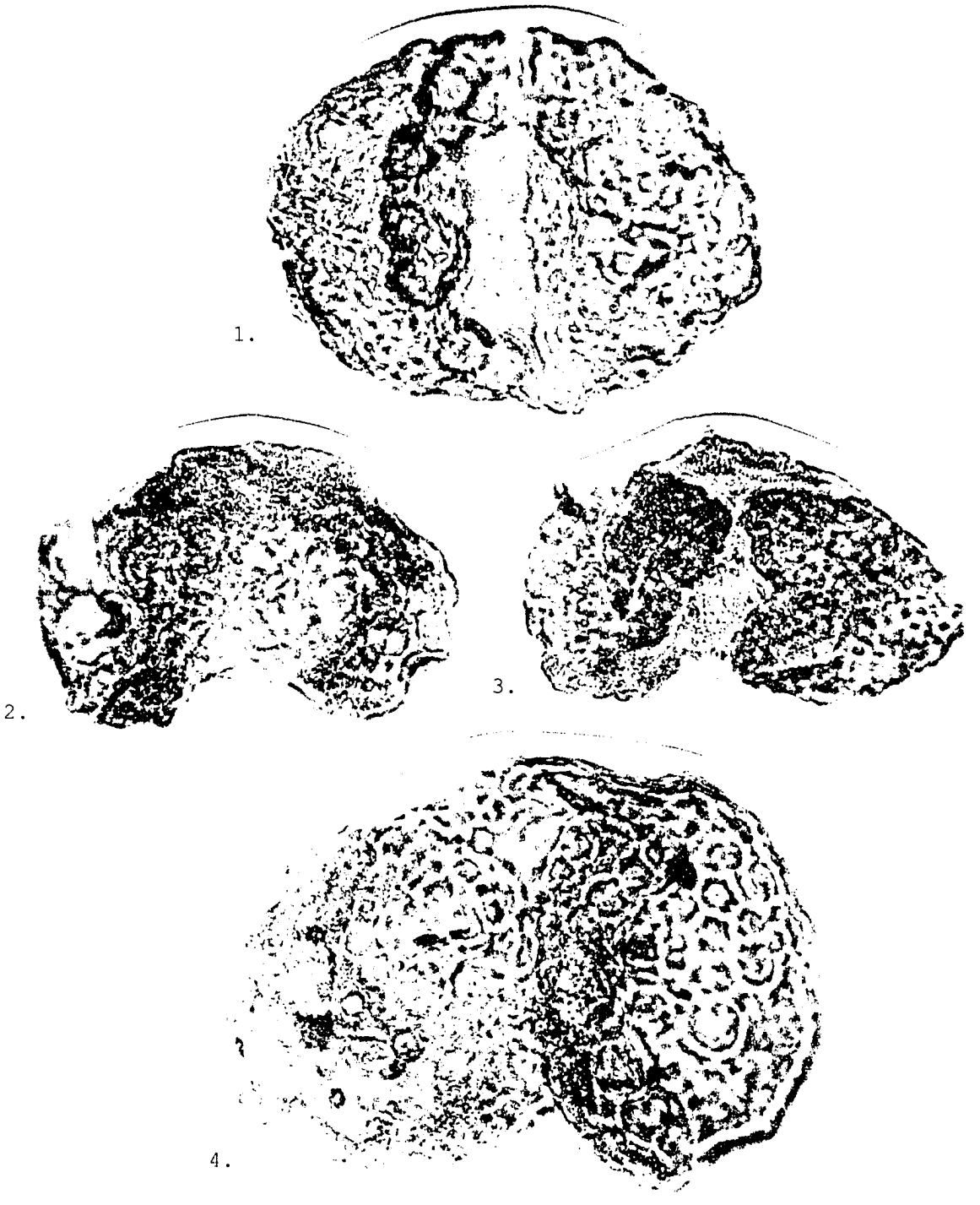


Plate 188

Slide Mountain Paleoflora

Slide No. 94SR SM07(1)

1. Cycad/Ginkgo sp.: R33-20, ↓, 31-32S

2. *Ephedrapites* sp.: R33-23, ↓, 29-30P

3. *Ephedrapites* sp.: R4-1a, ↓, 27T-U

Slide No. 94SR SM04(1)

4. *Fraxinoipollenites constrictus* (Pierce) Chlonova 1976: R34-28, ↓, 24H

Plate 188

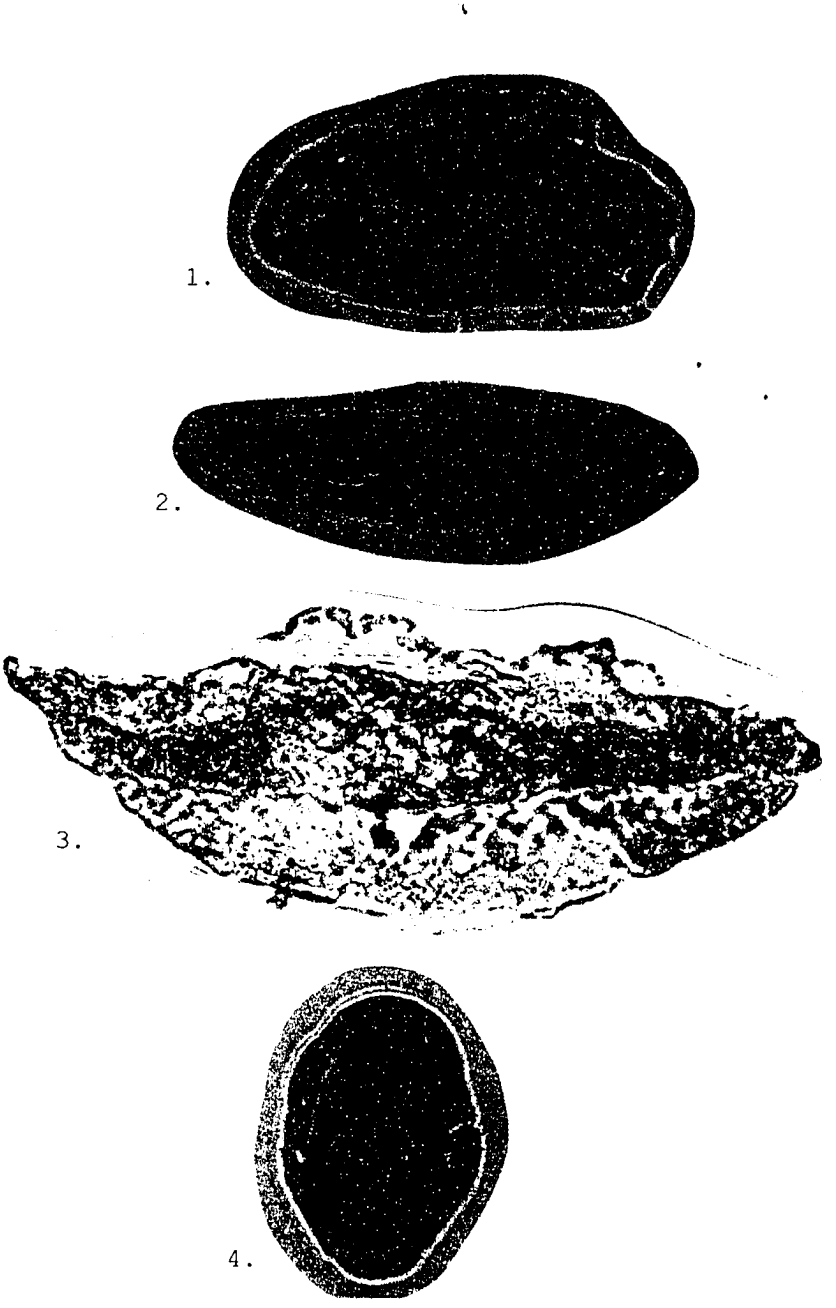


Plate 189

Slide Mountain Palynoflora

Slide No. 94SR SM07(1)

1. *Fraxinoipollenites* sp.: R33-19, ↓, 31R-S

2. *Eucommiidites troedssonii* Erdtman 1948: R32-19, ↑, 7L

3. *Nyssapollenites albertensis* Singh 1971: R33-28, ↓, 26G-H

Slide No. 94SR SM06(1)

4. *Alnipollenites verus* Potonié 1960: R4-31a, ↓, 24G-H

Slide No. 94SR SM04(2)

5. *Fraxinoipollenites constrictus* (Pierce) Chlonova 1976: R3-7a, ↓, 33-34L

Slide No. 94SR SM07(1)

6. *Triporopollenites* sp. cf. *T. mullensis* (Simpson) Rouse and Srivastava 1972: R4-6a, ↑, 7R

Slide No. 94SR SM04(1)

7. *Trudopollis hemiperfectus* (Pflug) Pflug, 1953: R3-15a, ↓, 22P-Q

Slide No. 94SR SM06(1)

8. *Cupanieidites major* Cookson and Pike 1954: R3-0a, ↓, 39M

Slide No. 94SR SM04(2)

9. *Oculopollis* sp.: R3-8a, ↑, 9T

Slide No. 94SR SM07(2)

10. *Retibrevitrocolporites beccus* Sweet 1986: R32-13, ↑, 7N-P

Slide No. 94SR SM06(1)

11. *Expressipollis ocliferius* Chlonova 1961: R6-20a, ↓ 29F

12. *Callistopollenites radiostriatus* (Mchedlishvili *in* Samoilovich and Mchedlishvili) Srivastava 1969: R6-16a, ↓, 32V

Plate 189

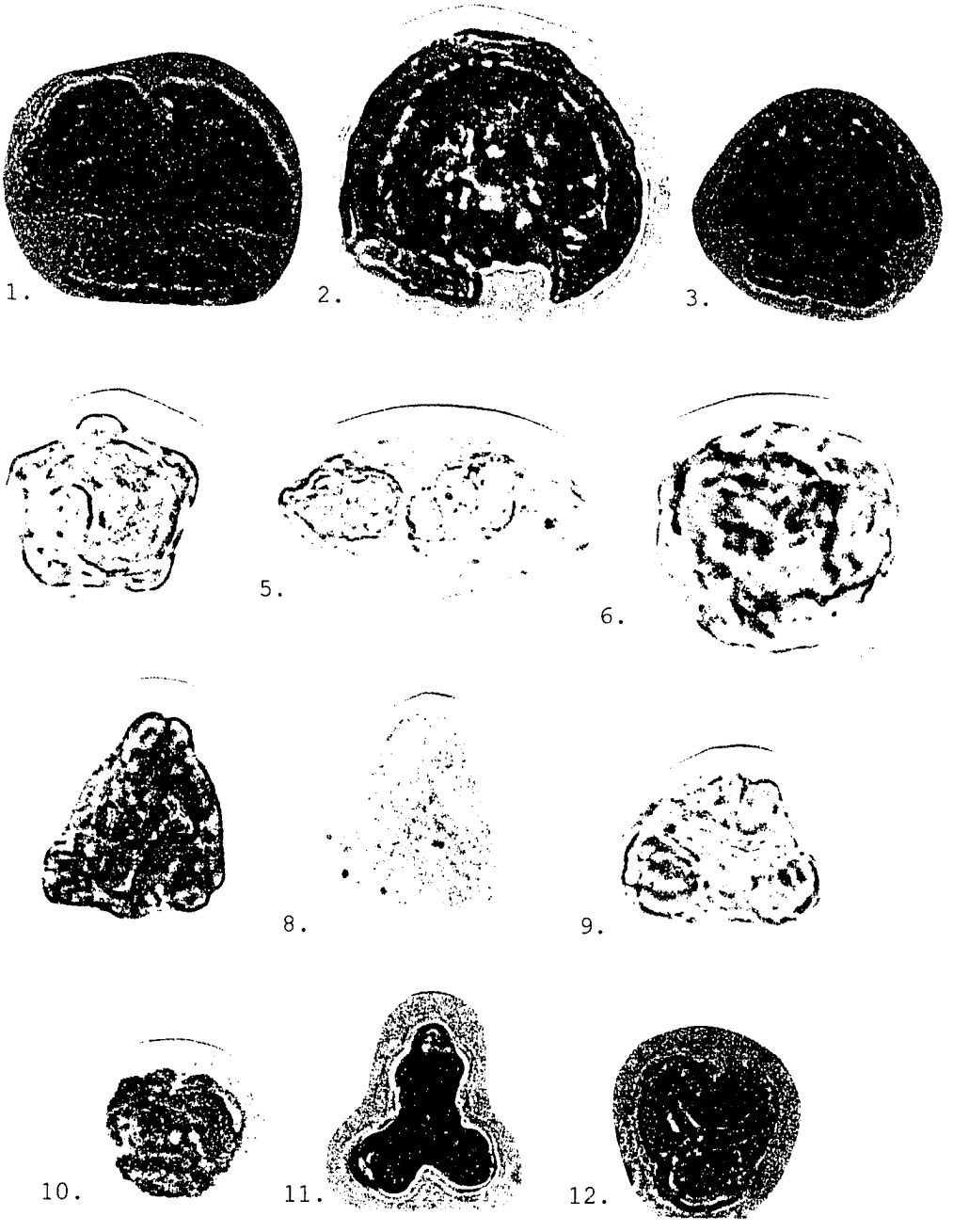


Plate 190

Slide Mountain Palynoflora

Slide No. 94SR SM06(1)

1. *Beaupreadites elegansiformis* Rouse 1957: R4-33a, ↓, 35-36C

Slide No. 19: 94SR SM06 (PSL-2)

2. *Beaupreadites* sp.: R4-24a, ↑, 16Q

Slide No. 94SR SM07(1)

3. *Proteacidites retusus* Anderson 1960: R4-1a, ↓, 27T-U

Slide No. 94SR SM06(2)

4. *Proteacidites* sp.: R4-22a, ↑, 7Q

Slide No. 20: 94SR SM07 (PSL-1)

5. *Proteacidites* sp.: R4-2a, ↓, 32K-L

6. *Proteacidites thalmanni* Anderson 1960: R4-4a, ↓, 34-U

7. *Proteacidites* sp.: R4-3a, ↓, 36-37H

Plate 190

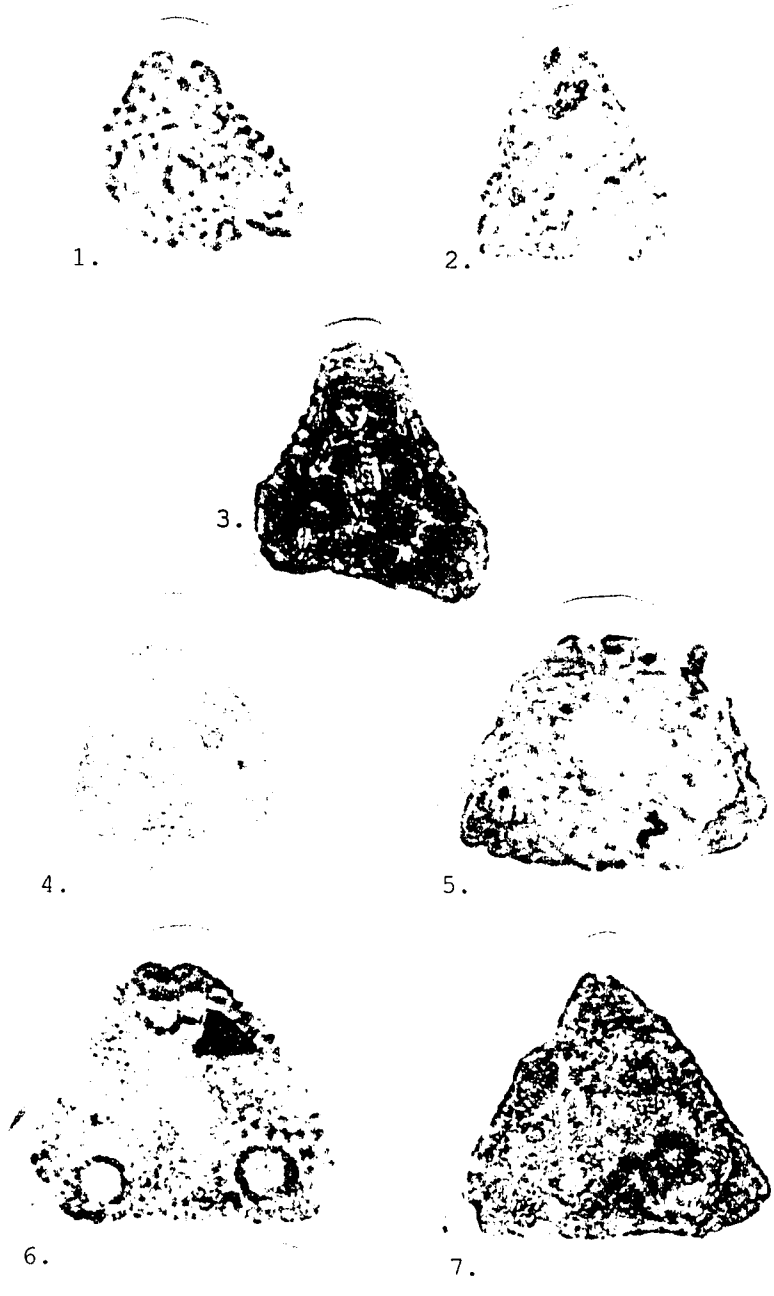


Plate 191

Slide Mountain Palynoflora

Slide No. 94SR SM06(1)
1. *Extratriporopollenites* sp.: R31-14, ↓, 40K

Slide No. 94SR SM06(2)
2. *Oculopollis orbicularis* Goczan 1964: R4-23a, ↑, 11S

Slide No. 94SR SM07(1)
3. *Aquilapollenites* sp. cf. *A. reticulatus* (Mtchedlishvili) Tschudy and Leopold 1971: R33-27, ↓, 26S

Slide No. 94SR SM04(1)
4. *Aquilapollenites delicatus* Stanley var. *delicatus* Tschudy and Leopold 1971: R3-11a, ↑, 14R

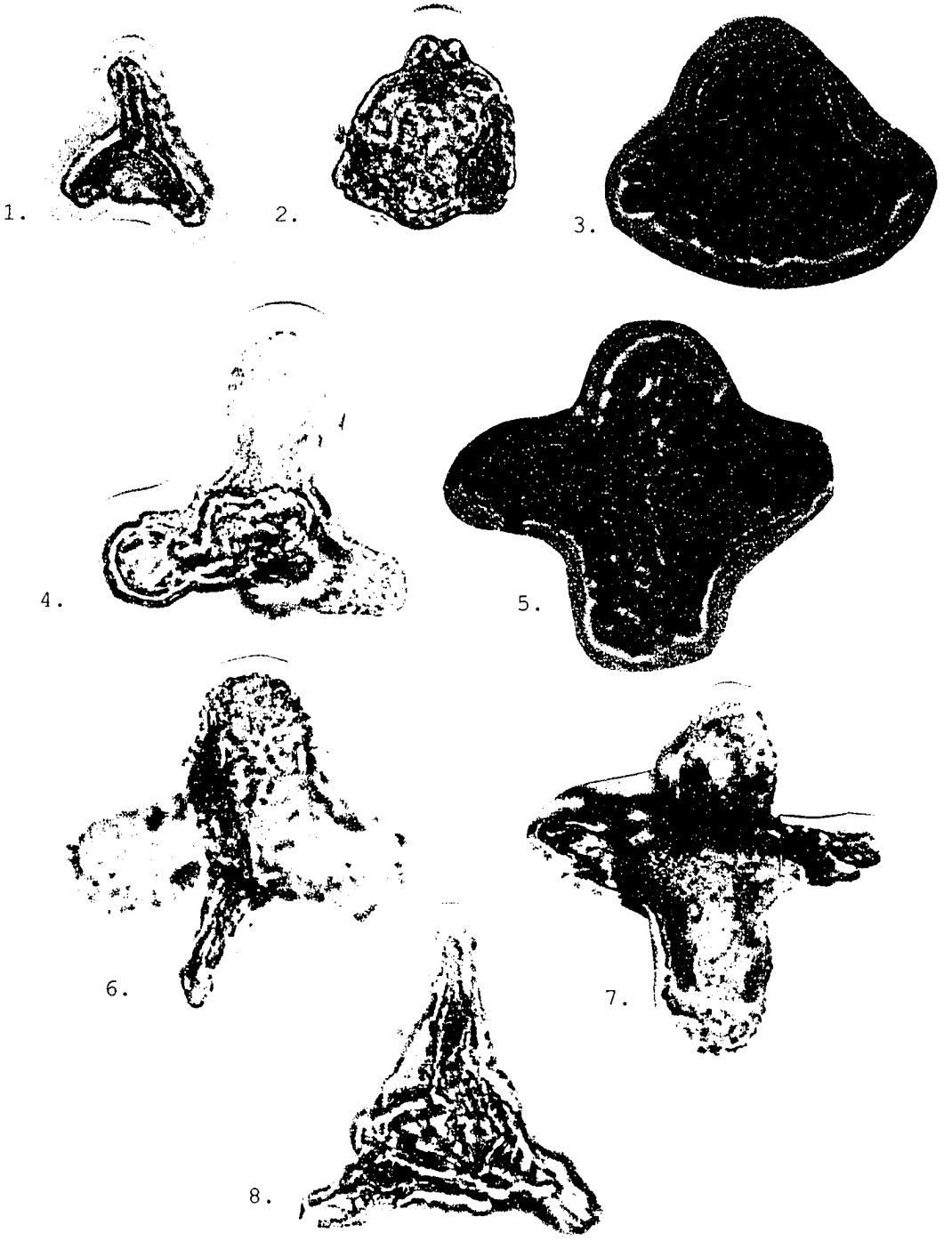
Slide No. 94SR SM07(1)
5. *Aquilapollenites sinulosus* Funkhouser 1961: R33-11, ↓, 39N

Slide No. 94SR SM04(1)
6. *Aquilapollenites polaris* Funkhouser 1961: R3-9a, ↑, 6-7H

Slide No. 94SR SM07(1)
7. *Aquilapollenites trialatus* Rouse 1957: R32-27/28, ↑, 11T

8. *Aquilapollenites conatus* Norton 1965: R4-0a, ↑, 7P

Plate 191



APPENDIX J
Photographic Plates

Granite Creek Palynomorphs

	POLLEN	
	Genus	**Species**
1	*Abietipites*	sp.
2	*Aquilapollenites*	*quadrilobus*
3	*Aquilapollenites*	*senonicus*
4	*Bombacacipites*	spp.
5	*Cedripites*	sp.
6	*Cranwellia*	*rumseyensis*
7	*Fraxinoipollenites*	*constrictus*
8	*Mancicorpus*	sp.
9	cf. *Pityosporites*	*alatipollenites*
10	cf. *Pityosporites*	*elongatus* var. *elongatus*
11	*Podocarpidites*	cf. *canadensis*
12	*Retibrevitrocolporites*	*beccus*
13	*Taxodiaceaepollenites*	*hiatus*
14	*Tricolpate*	spp.
15	*Trudopollis*	*hemiperfectus*

Plate 192

Granite Creek Palynoflora

Slide No. SR93 GrCK 004(1)
1. cf. *Pityosporites alatipollenites* (Rouse 1959) Singh 1964: R5-16a, ↑, 12H

Slide No. SR93 GrCK 001(1)
2. *Podocarpidites* sp. cf. *P. canadensis* Pocock 1962: R5-4a, ↑, 12J-K

Slide No. SR93 GrCK 001(2)
3. *Abietipites* sp.: R5-8a, ↑, 8P-Q

Slide No. SR93 GrCK 001(1)
4. *Cedripites* sp.: R5-0a, ↑, 3V-W

Slide No. SR93 GrCK 001(2)
5. cf. *Pityosporites elongatus* (Norton) var. *elongatus* Tschudy 1973: R5-6a, ↑, 5S-T

Slide No. SR93 GrCK 006(2)
6. *Taxodiaceaepollenites hiatus* (Potonié) Kremp 1949: R5-35a, ↑, 17F-G

Plate 192

Plate 193

Granite Creek Palynoflora

Slide No. SR93 GrCK 001(2)

1. *Cranwellia rumseyensis* Srivastava 1966: R5-10a, ↑, 17S-T

2. *Retibrevitrocolporites beccus* Sweet 1986: R5-7a, ↑, 8-9K

Slide No. SR93 GrCK 005(2)

3. *Trudopollis hemiperfectus* (Pflug) Pflug 1953b: R5-25a, ↑, 13-14E

4. Tricolpate sp.: R5-27a, ↑, 13S-14T

Slide No. SR93 GrCK 006(2)

5. *Bombacacipites* sp.: R5-29a, ↑, 1M

6. *Bombacacipites* sp.: R5-32a, ↑, 11V-12W

Slide No. SR93 GrCK 001(1)

7. *Fraxinoipollenites constrictus* (Pierce) Chlonova 1976: R5-3a, ↑, 5-6Q

Slide No. SR93 GrCK 006(2)

8. Tricolpate sp.: R5-36a, ↑, 19K

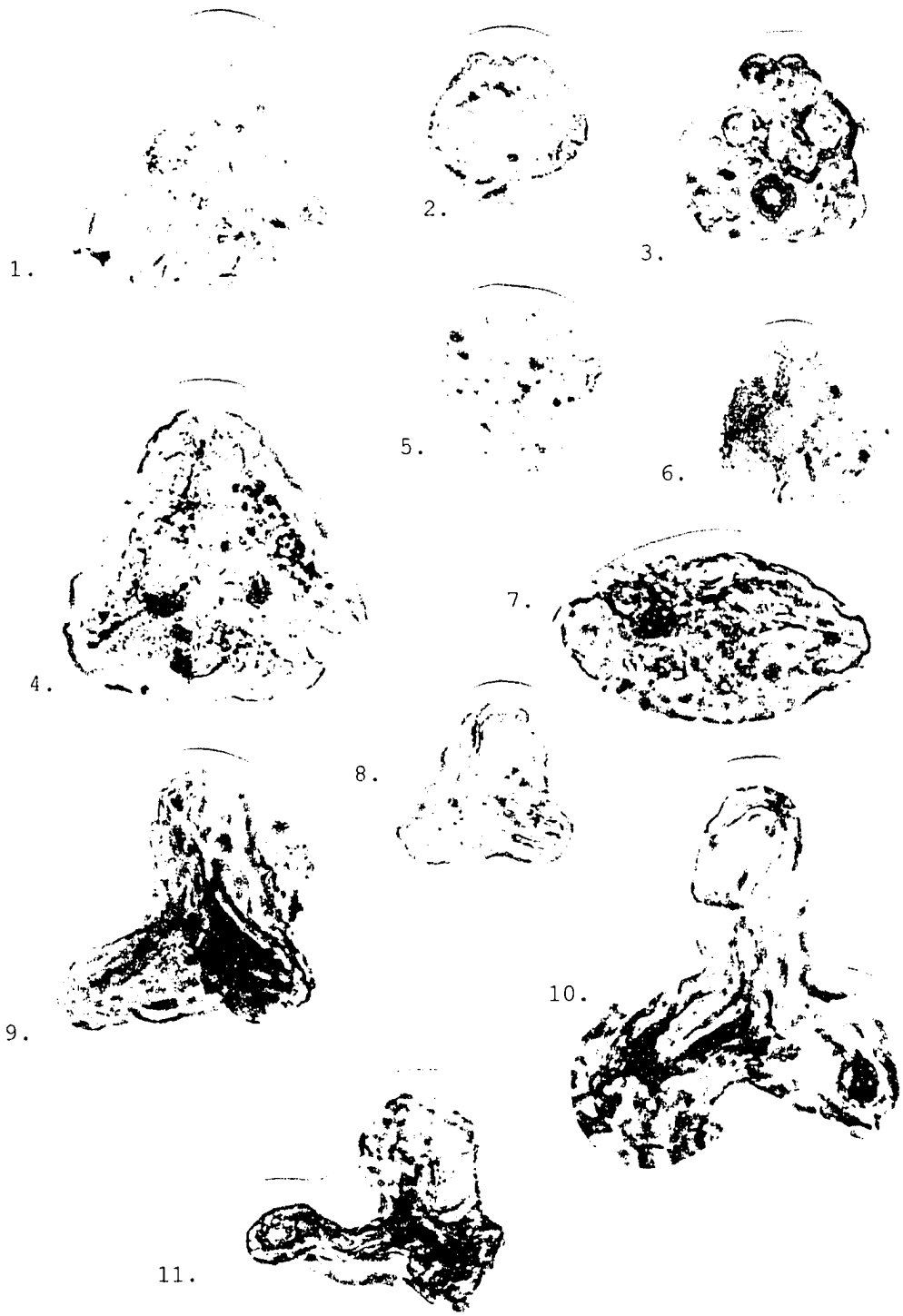
Slide No. SR93 GrCK 005(1)

9. *Aquilapollenites quadrilobus* Rouse 1957: R5-24a, ↑, 10D-E

10. *Mancicorpus* sp.: R5-23a, ↑, 3-4S

Slide No. SR93 GrCK 006(1)
11. *Aquilapollenites senonicus* (Mtchedlishvili) Tschudy and Leopold 1969: R5-28a, ↓, 17M

Plate 193



APPENDIX K
Spores and pollen species in the Matanuska Formation

Fungal spores:

Colligerites kutchensis (Kar and Saxena) Jain and Kar 1979
Dyadosporites substrangulatus(Salard-Cheboldaeff and Locquin) Kalgutar and Jansonius 2000
Fusiformisporites rugosus Sheffy and Dilcher 1971
Palambages canadiana Srivastava 1968
Pluricellaesporites magnus Rouse and Mustard 1997
P. sheffyi Martinex-Hernandex and Tomasini-Ortiz 1989

Spores:

Acathotriletes varispinosus Pocock 1962
Anemia paradoxa Bolkhovitina 1961
Appendicisporites bilateralis Singh 1971
A. potomacensis Brenner 1963
Aequitriradites spinulosus (Cookson and Dettmann) Cookson and Dettmann 1961
Baculatisporites comaumensis (Cookson) Potonié 1956
Biretisporites potoniaei Delcourt and Sprumont 1955
B. psilatus (Groot and Penny) Dettman 1963
Brevimonosulcites corrugatus Yu and Zhang 1987
Camarozonosporites ambigens (Fradkina) Playford 1971
C. australiensis Norvick and Burger 1975
C. insignis Norris 1967
Ceratosporites equalis Cookson and Dettmann 1958
C. levidensis (Balme) Burden and Hill 1989
C. couliensis Srivastava 1972
Cibotiumspora juncta (Karza-Murza) Singh 1989
C. juriensis (Balme) Filatoff 1975
Cicatricosisporites augustus Singh 1971
C. annulatus Archangelsky and Gamerro 1966
C. hallei Delcourt and Sprumont 1955
C. hughesi Dettmann 1963
C. imbricatus (Markova) Singh 1971
C. ornatus Srivastava 1972
C. pseudotripartitus (Bolkhovitina) Dettmann 1963

C. radiatus Krutzsch 1959
Cingulatisporites reticingulus Brenner 1963
Cingutriletes clavus (Balme) Dettmann 1963
Concavissimisporites punctatus (Delcourt and Sprumont) Brenner 1963
C. minor (Pocock) Delcourt, Dettmann and Hughes 1963
Concavitriletes mesozoicus Krutzsch 1959
Converrucosisporites cameronii (de Jersey) Playford and Dettmann 1965
Cornutisporites seebergensis Schultz 1962
Cyathidites australis Couper 1953
C. diaphana (Wilson and Webster) Nichols and Brown 1992
C. minor Couper 1953
Deltoidospora diaphana Webster and Wilson 1946
D. hallii Miner 1935
D. juncta (Kara-Murza) Singh 1964
D. neddeni (Potonié) Orbell 1973
D. psilostoma Rouse 1959
Dictyophyllidites harrisii Couper 1958
D. mortonii (de Jersey) Playford and Dettmann 1965
Distaltriangulisporites maximus Singh 1971
D. mutabilis Singh 1971
D. perplexus (Singh) Singh 1971
Duplosporis ocliferus (Chlonova) Bondarenko 1965
Echinatisporis solaris Braman 2001
Foraminisporis simiscalaris (Paden, Phillips and Felix) Braman 2001
F. undulatus Leffingwell 1971
F. wonthaggiensis (Cookson and Dettmann) Dettmann 1963
Foveosporites crassus Dorhofer 1977
Foveasporis linearis Krutzsch 1959
Foveogleicheniidites confossus (Hedlund) Norvick and Burger 1976
F. subtriangularis (Brenner) Doring 1966
Foveosporites crassus Dorhofer 1977
Foveotriletes palaequestrus Partridge 1973
Gemmatriletes morulus Pierce 1961
Gleicheniidites circinidites (Cookson) Brenner 1963
G. concavisporites (Rouse) Srivastava 1966
G. delicatus (Bolkhovitina) Pocock 1970
G. senonicus (Ross) Delcourt and Sprumont 1955
G. umbonatus (Bolkhovitina) Bolkhovitina 1968
Hamulatisporis amplus Stanley 1965
Hazaria canadiana Srivastava 1971
H. sheoparii Srivastava 1971

Hymenoreticulisporites castallatus (Pocock) Doring 1964
Interulobites intraverrucatus Brenner 1963
Klukisporites pseudoreticulatus Couper 1958
K. hastilobatus Playford 1971
K. reissingerii (Harris) Morby 1975
Laevigatisporites gracilis Wilson and Webster 1946
L. ovatus Wilson and Webster 1946
Leptolepidites crepitus Singh 1971
L. proxigranulatus (Brenner) Dorhofer 1979
L. verrucatus Couper 1953
Lycopodiacidites canaliculatus Singh 1971
L. caperatus Singh 1971
Lycopodiumsporites crassatus Singh 1971
L. crassimacerius Hedlund 1966
L. marginatus Singh 1964
L. singhii Srivastava
Lygodiosisporites verrucosus Srivastava 1967
Matonisporites crassiangulatus (Balme) Dettmann 1963
Microfoveolatosporis pseudoreticulatus (Hedlund) Singh 1983
Microreticulatisporites crassienxinous Brenner 1963
M. diatretus Norris 1969
M. uniformis Singh 1964
Neoraistrickia truncata (Cookson) Potonié 1956
Ornamentifera baculata Singh 1971
O. enchinata (Bolkhovitina) Bolkhovitina 1966
Osmundacidites wellmanii Couper 1953
Pilosisporites trichopapillosus (Thiergart) Potonié 1956
Polycingulatisporites reduncus (Bolkhovitina) Playford and Dettmann 1965
Psilatriletes radiatus (Brenner) Doring 1966
Reticulatasporites dupliexinous Brenner 1963
Reticulisporites semireticulatus (Burger) Norris 1967
Reticuloidosporites pseudomurii Elsik 1968
Retitriletes austroclavatidites (Cookson) Krutzsch 1963
R. clavatoides (Couper) Doring *et al.* 1963
R. crassimacerius (Hedlund) Burden and Hills 1989
R. lucifer Srivastava 1972
R. singhii Srivastava 1972
R. subreticulaesporites (Rouse) Krutzsch 1963
Rouseisporites triangularis Pocock 1962
Schizea reticulata Cookson 1956
Selaginella simplex Krasnova 1961
Sestrosporites pseudoalveolatus (Couper) Dettmann 1963
Stereisporities antiquasporites (Wilson and Webster) Dettmann 1963

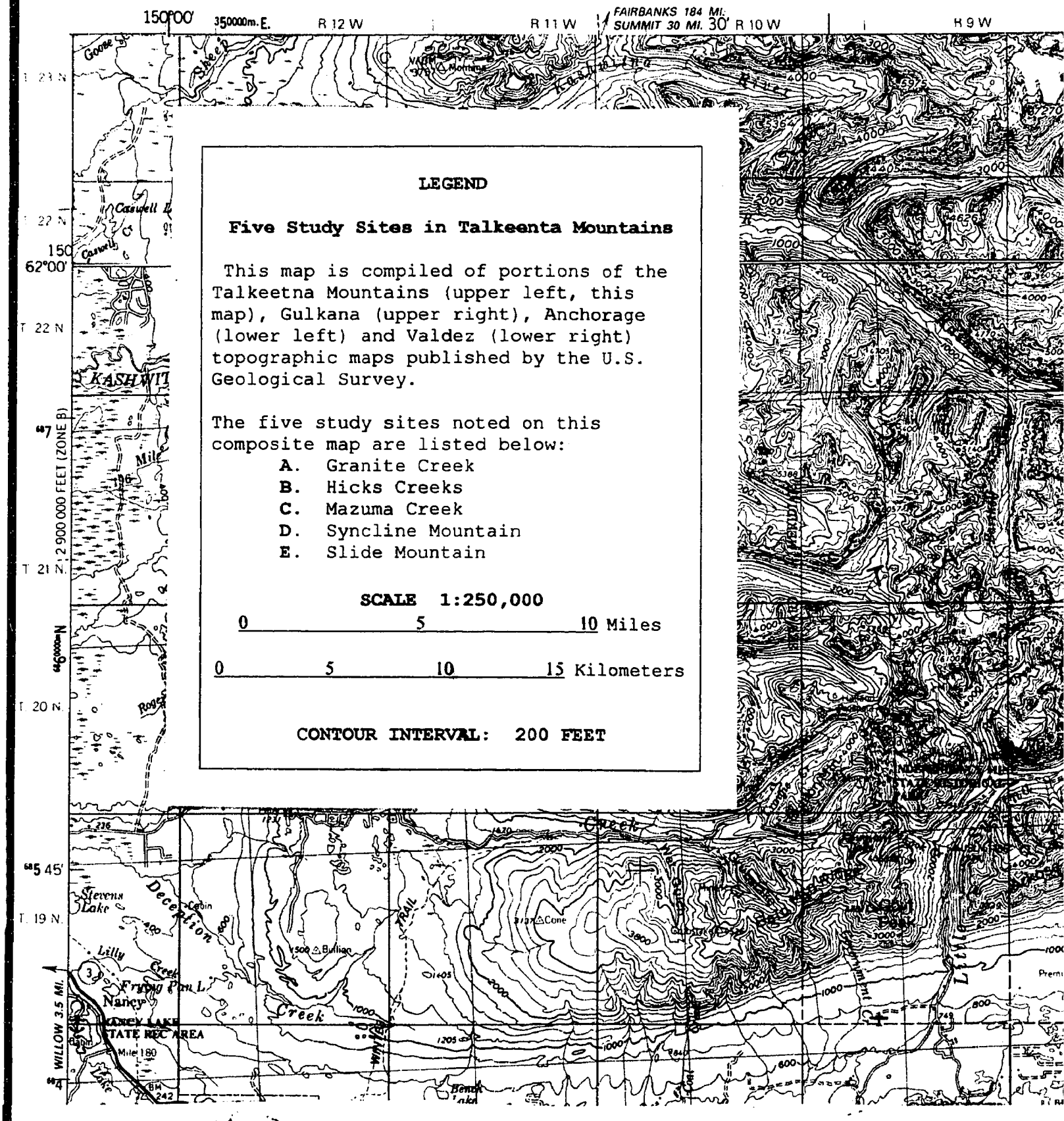
Taurocusporites segmentatus Stover 1962
Todisporites minor Couper 1958
Toroisporis delicatus Doring 1965
Trianchoraeosporites reticulatis Schultz 1962
Triplanosporites sinuosus (Pflug) Thompson and Pflug 1953
Triporoletes radiatus (Dettmann) Playford 1971
Umbosporites callosus Newman 1965
Undulatisporites fossulatus Singh 1971
Verrucosisporites major (Couper) Burden and Hills 1989

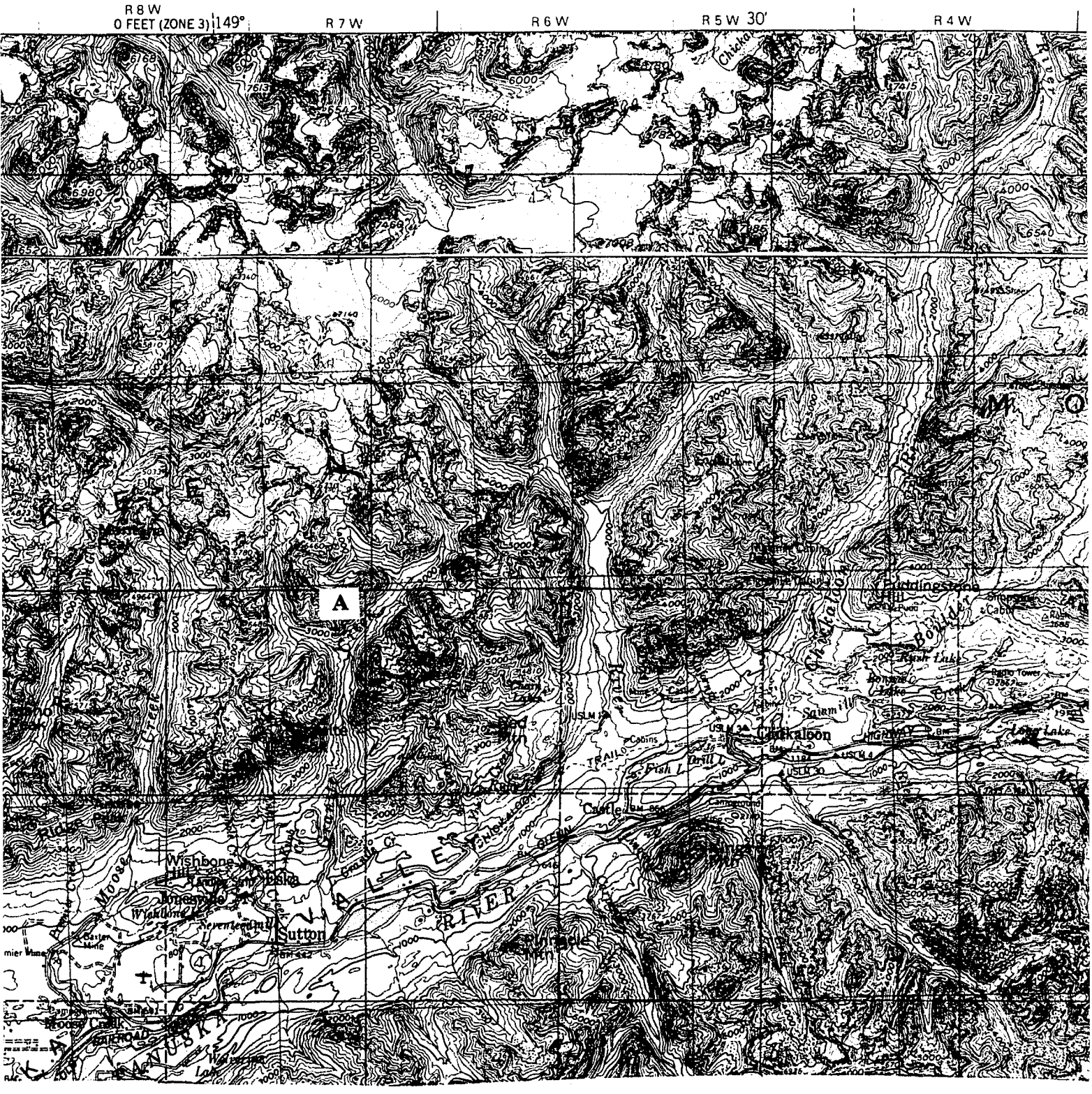
Pollen:

Abietineaepollenites microreticulatus Groot and Penny 1960
A. varius Norton *in* Norton and Hall 1969
Accuratipollis evanidus Chlonova 1961
Alisporites bilateralis Rouse 1959
A. grandis (Cookson) Dettmann 1963
A. microsaccus (Couper) Pocock 1962
Alnipollenites verus Potonié 1960
Aquilapollenites augustus Srivastava 1961
A. bertillonites Funkhouser 1961
A. catenireticulatus Srivastava 1968
A. conatus Norton 1965
A. contiguous Tschudy 1969
A. delicatus Stanley 1961
A. delicatus var. *delicatus* Tschudy and Leopold 1971
A. notabile (Mchedlishvili) Farabee 1990
A. polaris Funkhouser 1961
A. quadrilobus Rouse 1957
A. reticulatus (Mchedlishvili) Tschudy and Leopold 1971
A. scabratus Tschudy 1969
A. senonicus (Mchedlishvili) Tschudy and Leopold 1969
A. spinulosus Funkhouser 1961
A. reticulatus (Mchedlishvili) Tschudy and Leopold 1971
A. trialatus Rouse 1957
Beaupreadites elegansiformis (Cookson) Rouse 1957
Boehlensipollis sp. Krutzsch 1962
Bombacacipites nacimientoensis Anderson 1960
Callistopollenites comis Srivastava 1970
C. radiostriatus (Mchedlishvili) Srivastava 1969
Cedripites canadensis Pocock 1962
C. cretaceous Pocock 1962
C. parvus Norton and Hall 1969

Cranwellia rumseyensis Srivastava 1966
C. striata (Couper) Srivastava 1967
Cupanieidites major Cookson and Pike 1954
C. terrestris Braman 2001
Cycadopites reticulatus (Nilsson) Cornet and Traverse 1975
Dryadopollis sp. A Braman 2001
Erdtmanipollis albertensis Srivastava 1969
Eucommiidites troedssonii Erdtman 1948
E. minor Groot and Penny 1960
Expressipollis ocliferius Chlonova 1961
Fraxinoipollenites constrictus (Pierce) Chlonova 1976
Ilexpollenites obscuricostata (Traverse) Srivastava 1967
Liliacidites inaequalis Singh 1971
Mancicorpus albertensis Srivastava 1970
M. canadiana (Srivastava) Tschudy 1971
M. pulcher (Funkhouser) Srivastava 1972
M. rostratus Srivastava 1968
M. trapeziforme Mchedlishvili 1961
M. tripodiformis (Tschudy and Leopold) Tschudy 1973
Marcellopites basilicus Srivastava 1969
Momipites inaequalis Anderson 1960
Nyssapollenites albertensis Singh 1971
N. bindae Srivastava 1969
Nyssoidites anulatus (Chlonova) Sweet 1986
Oculopollis orbicularis Goczan 1964
Parvisaccites radiatus Couper 1958
P. rugulatus Brenner 1963
P. amplus Brenner 1963
Penetetrapites inconspicuus Sweet 1986
Phyllocladites microreticulatus Brenner 1963
Pinuspollenites constrictus (Singh) Wingate 1980
Pityosporites alatipollenites (Rouse) Singh 1964
P. constrictus Singh 1964
P. elongatus var. *grandis* Tschudy 1973
Podocarpidites biformis Rouse 1957
P. canadensis (Pocock) Singh 1971
P. ellipticus Cookson 1947
P. epistratus Brenner 1963
P. *granulatus* Singh 1971
P. minisculus Singh 1964
P. multesimus (Bolkhovitina) Pocock 1962
P. potomacensis Brenner 1963
P. radiatus Brenner 1963
Proteacidites auratus Srivastava 1969
P. retusus Anderson 1960

P. thalmanni Anderson 1960
Quercoidites sternbergi Srivastava 1967
Quercus explanata Anderson 1960
Retibrevitricolporites beccus Sweet 1986
Retitricolpites georgensis Brenner 1963
R. maximus Singh 1971
R. vulgaris Pierce 1961
Rousea subtilis Srivastava 1970
Rugubivesiculites reductus Pierce 1961
Scollardia trapaformis Srivastava 1966
Sequoia papillapollenites (Rouse) Srivastava 1969
Spermatites sp. Miner 1935
Striatellipollis(striatella) radiata (Krutzsch) Sweet 1986
Taxodiaceaepollenites hiatus (Potonié) Kremp 1949
T. vacuipites (Wodehouse) Wingate 1980
Tilia wodehousei Anderson 1960
Tricolpites micromunus (Groot and Penny) Singh 1971
T. microreticulatus Belsky, Boltenhagen and Potonié 1965
T. reticulatus Cookson 1947
T. parvus Stanley 1965
Triporopollenites mullensis (Simpson) Rouse and Srivastava 1972
Trudopollis hemiperfectus (Pflug) Pflug 1953
T. pertrudens (Thomson and Pflug) Pflug 1953
Ulmoideipites herbridicus (Simpson) Sweet 1986
Vitreisporites pallidus (Reissinger) Nilsson 1958
Wodehouseia capillata Wiggins 1976
W. gracile (Samoilovitch) Pokrovaskaya 1966

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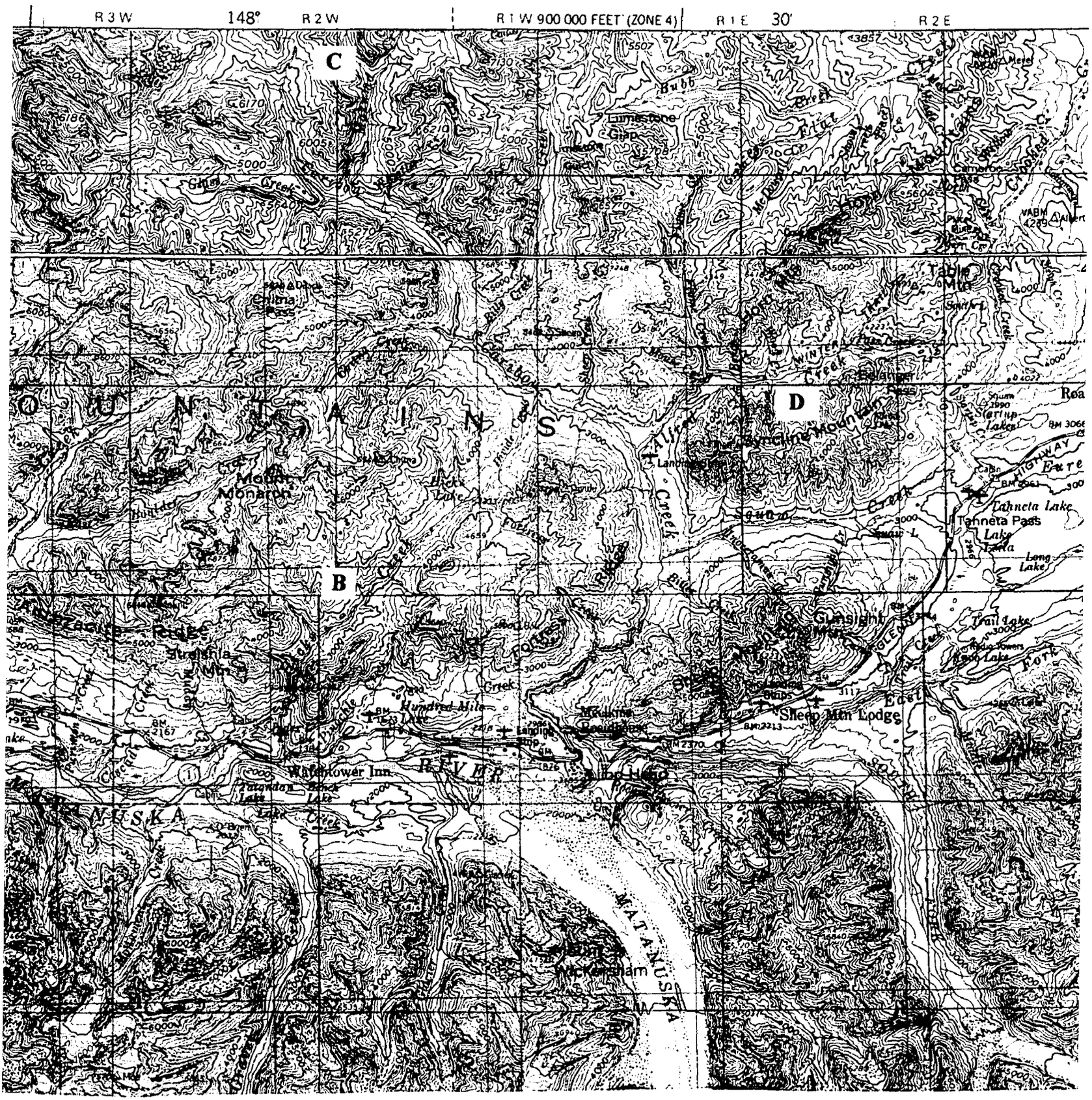
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